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Thyroid doses received in Belarus from the Chernobyl accident: Effects of personal data on thyroid doses.

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THYROID DOSES RECEIVED IN BELARUS FROM THE CHERNOBYL ACCIDENT: EFFECTS OF PERSONAL DATA ON THYROID DOSES.

Marianne Vidal, Victor Minenko, Sergey Shinkarev, Valeri Khrouch, Yuri Gavrilin, Paul Voillequé, André Bouville, Nick Luckyanov

1. Introduction

The Chernobyl accident occurred on the 26th of April 1986. Releases from the power plant resulted in a widespread contamination of the environment with radioactive materials in Europe, especially with radioiodines and radiocesiums. This environmental contamination led to substantial radiation doses in the thyroids of many inhabitants of the Republics of Belarus, Russia and Ukraine [UNSCEAR, 2000].

A zone of 30 km around the facility in Belarus and Ukraine was evacuated. Within a few weeks after the accident, gamma exposure rates were measured against the neck of more than 200,000 people in the Republic of Belarus, and among them 40,000 children 0-18 years old, in the more contaminated territories. Interviews were conducted in 1988 of more than 100,000 residents in order to collect information on the conditions of exposure in the various areas that were contaminated [Minenko et al., 2000].

Initial thyroid dose estimates were calculated on the basis of these direct thyroid measurements and of the available information on conditions of exposure in the contaminated areas [Gavrilin et al., 1999].

In the 1990s, a Belarussian-American epidemiological study of thyroid deceases was designed and undertaken among 12,000 people who were 0 to 18 years old at the time of accident, and whose thyroid exposure had been measured in May-June 1986 [Wachholz, 1994; Beebe, 2003]. All members of this cohort have been interviewed at least once between 1997 and 2001.

Therefore, large number of records describing Belarussian people's habits, relocation histories and consumption of milk are available. The different databases are currently reviewed and completed in the Institute of Biophysics, Moscow, and their final version is expected for 2005. Because the databases used in this report are not in their final version, the purpose of this report is not to give any recommendation about future available information on direct thyroid measurement. However it seemed interesting to perform a first analysis on the preliminary thyroid doses due to ^{131}I in order to check the consistency of the currently available results. Thus the purposes of this analysis are to identify biases in the measurements and to evaluate the variability of measurements results for children whose thyroid activities were assessed and whose doses were estimated. This study could be re-done after the revised databases are completed.

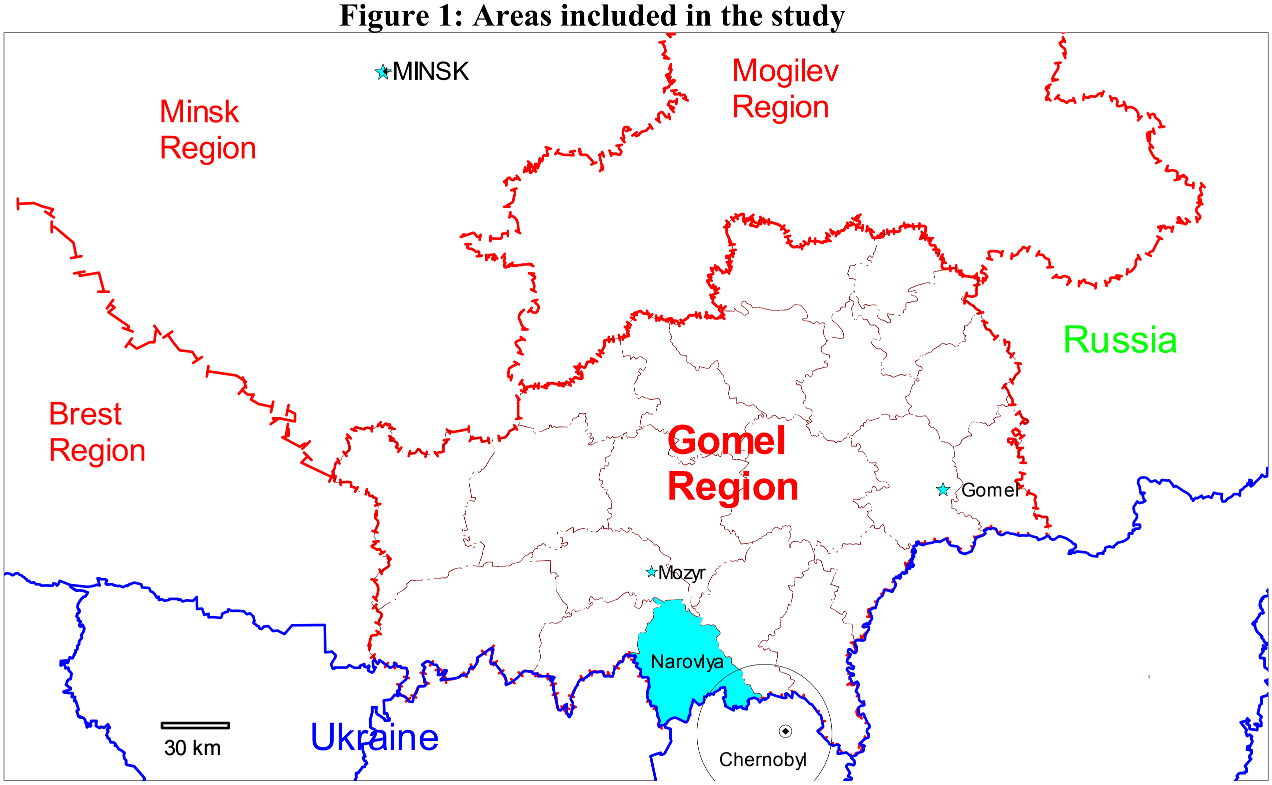
We decided to focus on the preliminary thyroid doses due to ^{131}I to Belarussian people, and especially children from 0 to 18 years old at the moment of the Chernobyl accident (born between 1968 and 1986). Two areas are considered: a rural area close to the site of the accident, where the thyroid doses were found to be very large (up to 3,600 cGy) and an urban area far from the site of the accident, were the thyroid doses were relatively small (up to 160 cGy).

2. Materials and methods

2.1. Description of the areas and of characteristics of the radiation exposures

Data regarding two sets of people with direct thyroid measurements, i.e. with measurement of the activity near their thyroid gland, were analyzed. The first one consists of those who were living at the time of the accident in Narovlya district ("raion"), a rural area in Gomel region ("oblast") which population counted 27,600 people at the time of the accident [Institute of Radiation Medicine, 1990]. The district was partly in the 30 km zone and some of its settlements, i.e. the place where people lived at the moment of the accident, were evacuated before 4 May 1986 (cf. Figure 1). Direct thyroid measurements, which consisted of activity measurement near to the thyroid gland, were performed on 12,773 inhabitants (46 %). In this rural area, the main pathway for activity due to the fallout was the consumption of fresh milk. Stable iodine pills for prophylaxis purposes were available, but were generally taken too late, and few individual data are available. Narovlya district database was subdivided in three parts, according to the kind of settlement: evacuated villages, nonevacuated villages and Narovlya town.

Figure 1: Areas included in the study



Available fallout data described ^{137}Cs depositions. It was assumed to be roughly proportional to ^{131}I fallout, with proportionality factor variations from one village to another. We localized almost all the settlements of Narovlya district database on a map of ^{137}Cs fallout after the Chernobyl accident [Germenchuk, 2000]: from 37 to more than 1,480 kBq.m^{-2} (1 to 40 Ci/km^2), and verified that they were similar to the values given in other publications [Drozdovich et al., 1989; Gavrilin, 2002] (cf. Table 1 and Table A4 in Annexes). Some settlements from nonevacuated villages database were in the 30 km evacuated area because they were evacuated too late.

Table 1: Distribution of settlements from Narovlya district and number of inhabitants with direct thyroid measurement (DTM), according to the level of ^{137}Cs deposition (kBq.m^{-2}) [Germenchuk, 2000]

^{137}Cs deposition (kBq.m^{-2})	# of settlements	# of inhabitants with DTM
37 – 185	7	368
185 - 555	17	2,128
555 – 1,480	28	8,346
> 1,480	10	1,658
unknown	15	273
Total	**77**	**12,773**

The second set of people consists of those who were living in Minsk city in 1986, outside the 30 km zone of evacuation, farther North of Chernobyl Nuclear Power Plant. At the time of the accident, the city counted 1,500,000 inhabitants [Gavrilin et al., 1999]; 20,041 (1 %) among them were subjected to direct thyroid measurements in May and June 1986. The fallout on this urban area was less important: according to *the Atlas of caesium deposition on Europe after the Chernobyl accident* [Commission Européenne, 1998], the ^{137}Cs level in Minsk city was between 2 and 4 kBq.m^{-2} (0.054 Ci/km^2 and 0.1 Ci/km^2).

2.2. Description of the databases

Three sources of data were used: records from direct thyroid measurements performed in May-June 1986, information obtained during the first round of interviews in 1988 and information obtained for members of the Belarussian-American cohort.

2.2.1. Data from direct thyroid measurements

Because of the lack of special equipment for rapid monitoring of human thyroids, measurements of the ^{131}I content in thyroids of Belarussian inhabitants were done with very simple instruments with output in exposure or count rates, like DP-5, SRP-68-01 and DRG3-02, in May and June 1986. Confidence intervals and limit of detection were not very good in field conditions. The main purpose of this measurement campaign was to reach a large number of people in order to rapidly assess the consequences of the accident. Thus measurements were carried out at a number of fixed locations in central hospitals, as well as sanatoria, rest houses, summer camps for children, other facilities and even by mobile teams. In Belarus, more than 200,000 people were measured in this way within a few weeks after the accident [Gavrilin et al., 1999].

Direct thyroid measurements were performed in various conditions in Narovlya district and Minsk city, and were handwritten in different notebooks, sometimes very imprecisely. The information contained in notebooks was later computerized. At that occasion, conditions of measurement for each individual were recorded as much as possible:

- An index, called hereafter "IDIndex", was created using a combination of letters and numbers to identify the place of measurement (kind of institute or settlement or any other available information), and to identify the kind of device, if known;
- Some dates of measurement were not recorded in the notebooks. Therefore people who enter the information had restored them, matching with others measurements. These dates of measurement are called "restored dates".

Recorded data from direct thyroid measurement consisted in:

- Date of measurement: date when direct thyroid measurement was performed (or "restored date"),
- "Measure rate": value of the measured exposure rate against the thyroid, after deduction of the background,
- "Rate": value of the corrected exposure rate which takes into account some bias due to the measurement method, "
- IDIndex: reference record (place of measurement and instrument).

The conditions of measurements were characterized also by very "dirty" environment in term of activity in the background. These high levels of activity were at the origin of numerous misreading, because background level of activity was subtracted from activity measured near to the thyroid gland: the value zero was then recorded as exposure rate.

2.2.2. Data from 1988 interviews

Preliminary estimates of thyroid doses were obtained on the basis of the direct thyroid measurements and of information on the conditions of exposure to radioiodines that were determined during the interview campaign of 1988 [Gavrilin et al., 1999]. The questionnaires used in 1988 included the following five questions:

1. Where did you live from 26 April 1986 through 31 May 1986? Indicate the dates of residence in each village.
2. What was the date when cows (goats) were put on pasture in your village in 1986? What was the origin of fresh milk that you were drinking at that time?
3. What was the daily rate of your consumption of fresh milk between 26 April 1986 and 31 May 1986?
4. What was the date when you started taking potassium-iodide pills?
5. What was the date when you stopped to consume fresh milk?

Only inhalation during cloud passage and ingestion of fresh milk were considered as contributors to the thyroid dose resulting from the intake of ^{131}I.

The databases that combined results of 1988 interviews and individual thyroid doses assessments were computerized by the Biophysics Institute of Moscow. They contained the following fields (cf. Table A1 in Annexes) [Shinkarev, 1999]:

- Personal data: individual code for each person, district, settlement (place of habitation), profession and year of birth,

- Evacuation data: date when the person left the settlement,
- Milk data: date when cows began to consume pasture grass, daily rate of consumption of fresh milk between April 26, 1986 and May 31, 1986, and date when the person stopped consuming fresh milk,
- Iodine prophylaxis data: date when the person started taking potassium-iodide pills, and number of days when the person took KI pills,
- Recorded data from direct thyroid measurement (date, measure rate, rate and IDIndex)
- "Dose": thyroid dose assessment deducted from the "rate" and personal data,

2.2.3. *Data from Belarussian-American study cohort*

Not all the fields from the databases were completed for some persons. Data from further interviews conducted on the Belarussian-American study cohort, for people who belong simultaneously to the cohort and the databases were added for further analysis purposes. The Research Institute of Radiation Medicine and Endocrinology in Minsk, Belarus made this information available.

Thus we created the field "gender" for Narovlya district and Minsk city databases, and we filled in as much as possible the field "milk consumption" for children included in the Minsk city database. The information on gender was deducted from the full name of the person recorded in the Belarussian-American study, when it was possible, i.e. when names were not shortened. In some cases, the truncation of the name didn't allow to determine the individual's gender. Thus, in Narovlya district database we added the field "gender" for 4,405 males and 5,085 females. However milk consumption data were not available for people from Narovlya town either in the original Narovlya district database or in the results of the Belarussian-American study cohort. We completed the Minsk city database as much as we could with data on gender for 3,745 males and 5,635 females, and milk consumption for 1,878 children from the Belarussian-American cohort.

2.2.4. *Additional information*

Only direct thyroid measurements on people were performed, therefore measurements of ^{131}I activity in milk, soil, grass, leafy vegetables, crops and so on are not available. Indeed, the number of samples collected for spectrometric measurement over the Belarus territory during the months of May and June 1986 is 2,774; 65 % of these were from soil, 20 % from grass and 5,7 % from fresh milk [Gavrilin, 1997]. The sample collection took place primarily in the most contaminated areas, i.e. Mogilev and Gomel regions. The results of soil measurement showed that ^{131}I to ^{137}Cs ratios, recalculated to 26 April 1986, varied from 1 to 90. In Narovlya district, 249 samples from the environment and food were measured (cf. Table 2), and in Minsk region, less contaminated, only 42 samples were collected (20 from soil, 9 from grass, 8 from fresh milk and 5 from peat).

Table 2: Number and type of environmental and food samples collected in Narovlya district for spectrometric analysis [Gavrilin, 1997]

Month of measurement	Number of samples	Type of sample
May	36	soil
	33	grass
	17	fresh milk
	10	beef
	3	water
	3	sorrel
	2	pork
	1	soft cheese
	1	straw
	1	river sediment
	1	yolk
	1	dung
	1	onion
	1	rye
	1	silo
June	43	soil
	2	grass
	1	fresh milk
	3	peat
	1	grass flour
July	73	soil
	14	grass
Total	**249**	

2.2.5. Structure of the resulting database

The Narovlya district database was divided in three parts (cf. Figure 2):

- People from Narovlya town: 5,312 persons including 3,673 adults and 1,634 children. A lot of fields were empty, especially concerning profession, milk consumption, iodine prophylaxis, measured exposure rate and the year of birth was not recorded for 5 people. But all of 5,307 people with birth year and with direct thyroid measurement, and thus dose assessment, were kept in the study.
- People from nonevacuated villages in Narovlya district, or from villages evacuated after 4 May 1986: 15,424 persons. Only 6,321 people (5,131 adults, 1,190 children) were both measured in May-June 1986 and interviewed in 1988.
- People from villages in Narovlya district evacuated before 4 May 1986: 2,006 persons. A lot of these people who were interviewed in 1988 were not subjected to a thyroid activity measurement in May-June 1986. So only 968 people among them (841 adults, 127 children) were included in the study.

The Minsk city database provided less information than the Narovlya district database. We only considered 17,842 inhabitants who did not leave Minsk city during a few first weeks after accident; they were measured once in Minsk polyclinics (cf. Figure 3). 11,484 adults and 6,335 children were in that group.

Figure 2: Available information for people from Narovlya district

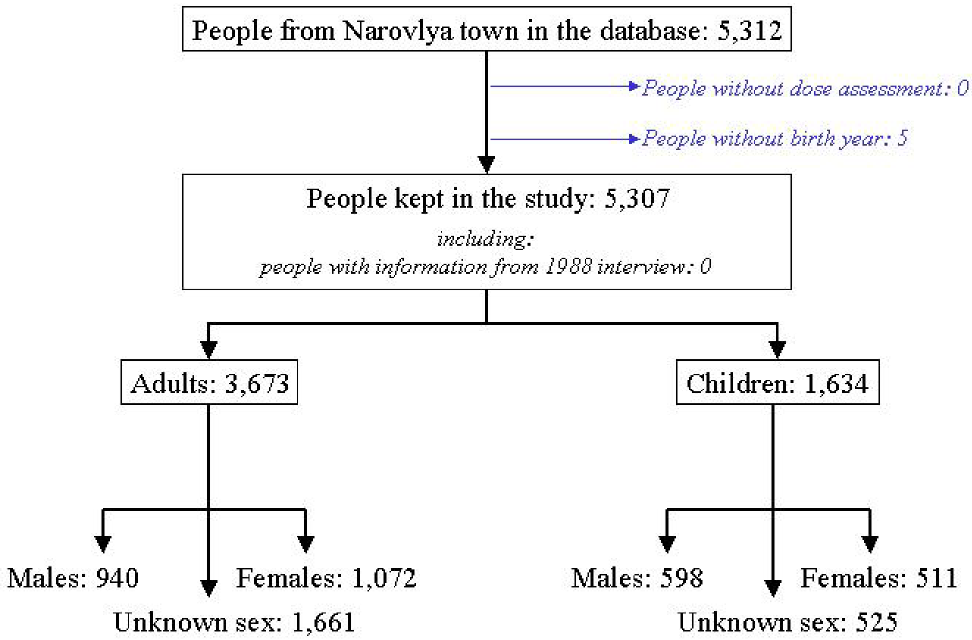
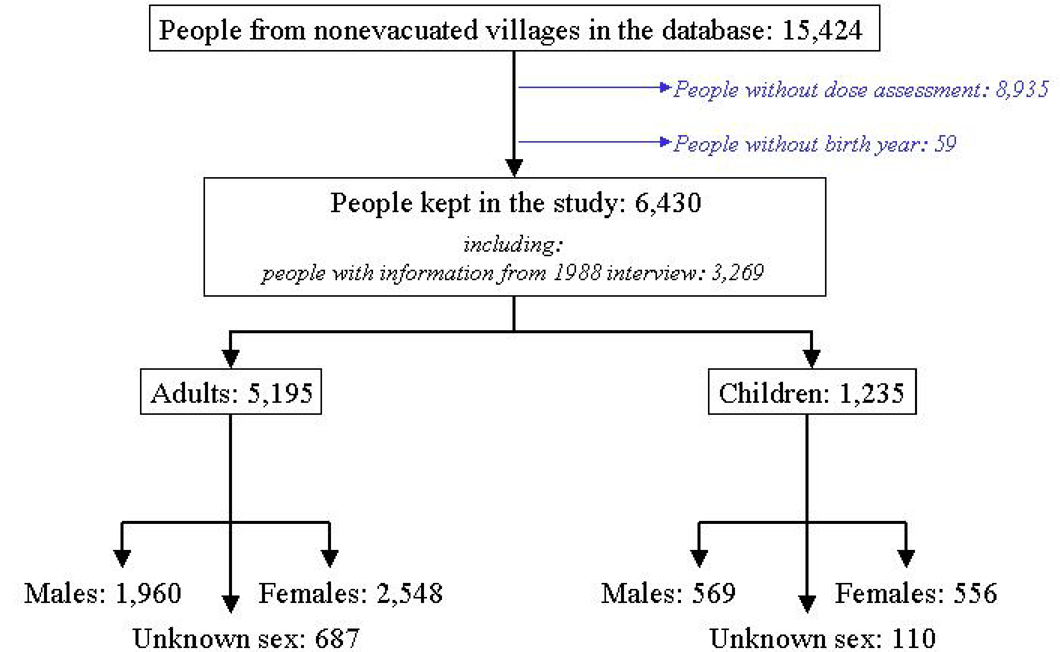


Figure 2 (continued): Available information for people from Narovlya district



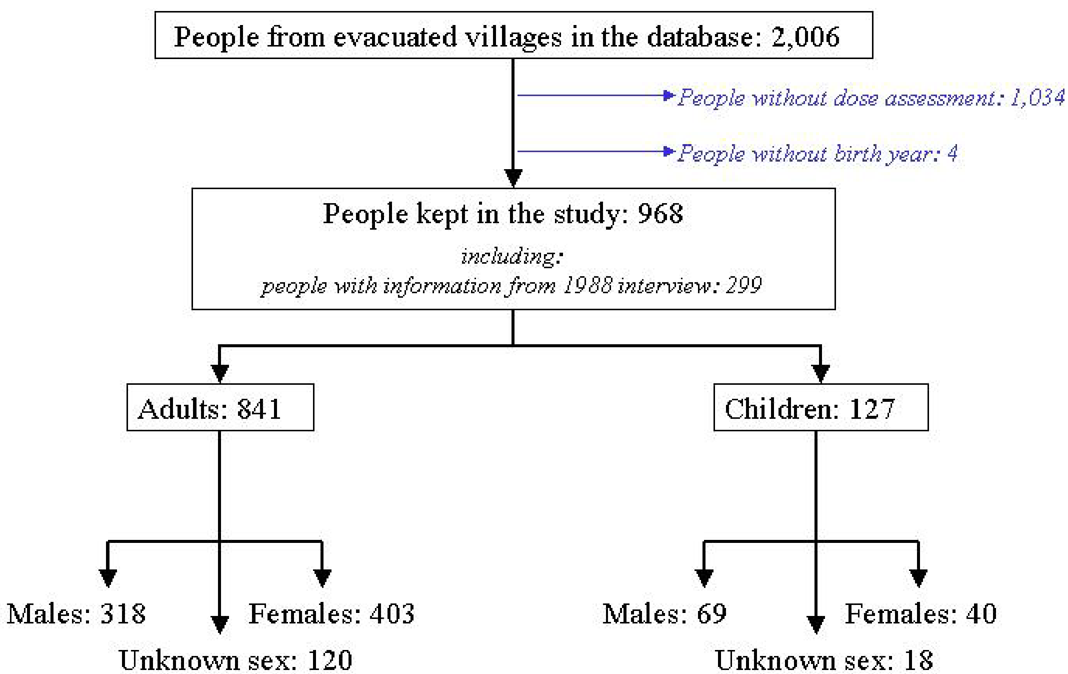
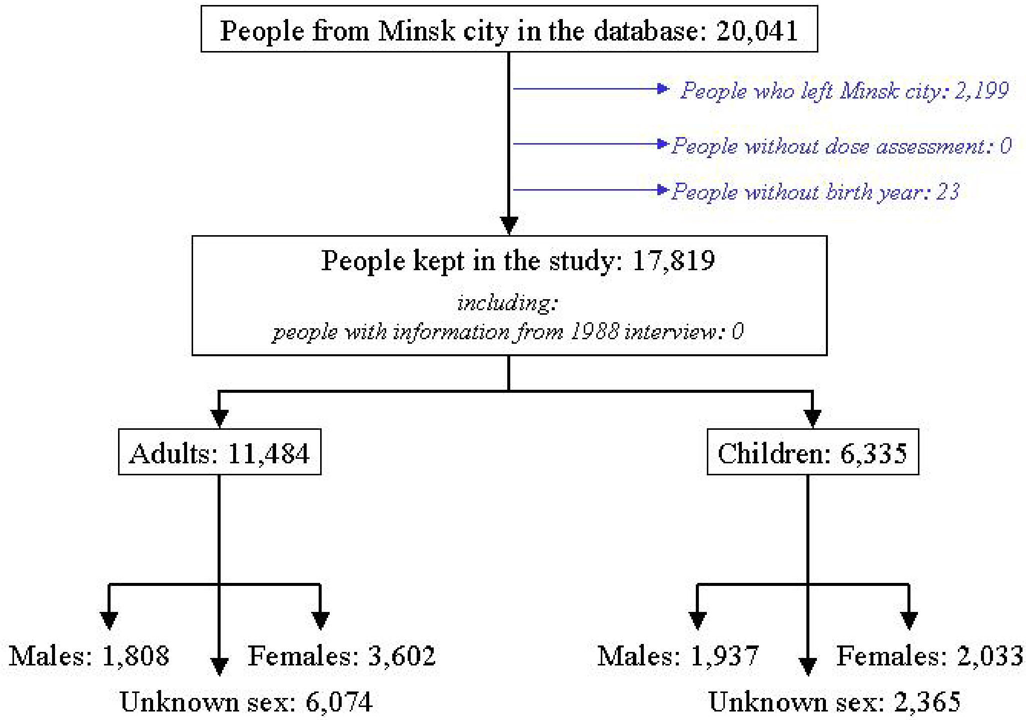


Figure 3: Available information for people from Minsk city



2.3. Estimation of the preliminary thyroid doses

It was assumed for the initial thyroid doses estimates that only ^{131}I was present in the thyroid at the time of measurement. The ^{131}I activity $G(t_{meas}, i)$ in the thyroid gland of an individual i at the time of measurement t_{meas} was calculated according to the formula (in Bq) [Gavrilin, 1999]:

$$G(t_{meas}, i) = cc(i) \times [P_{th}(t_{meas}) - P_b(t_{meas})]$$

where: $cc(i)$ is a calibration coefficient relating to the ^{131}I activity in the thyroid to the indication of the measuring instrument (Bq.h.μR^{-1} or Bq.h.mR^{-1}), and depends upon the age (with which thyroid volume changes),
$P_{th}(t_{meas})$ is the exposure rate measured near the thyroid (μR.h^{-1} or mR.h^{-1}),
$P_b(tm_{eas})$ is the background exposure rate (μR.h^{-1} or mR.h^{-1}).

The thyroid dose from the time of measurement to infinity, $D_0(t_{meas}, i)$ was then estimated assuming that there was no further ^{131}I intake after the measurement, according to the formula (in Gy) [Gavrilin, 1999]:

$$D_0(t_{meas}, i) = d(i) \times G(t_{meas}, i)$$

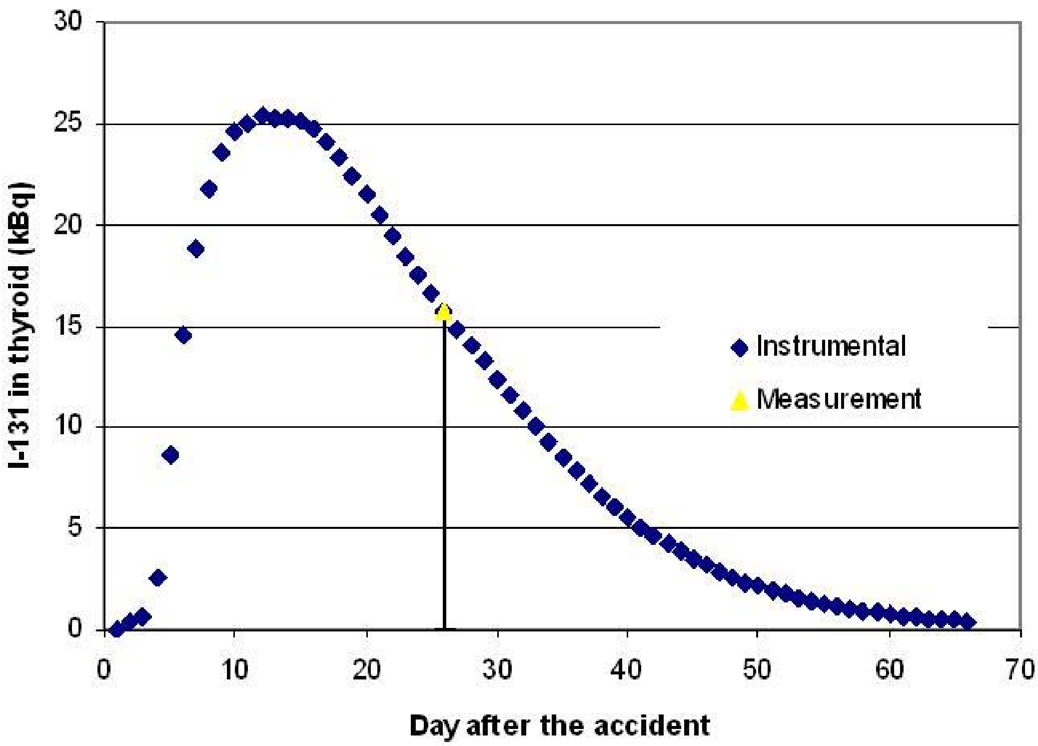
where: $d(i)$ is an age-dependent coefficient (Gy.Bq^{-1}).

Furthermore it was assumed that there was a single occurrence of fallout at a time that varied according to the region considered. The thyroid dose $d_{meas}(i,\ cc)$ was estimated according to (in Gy) [Gavrilin, 1999]:

$$d_{meas}(i, cc) = f(t_{meas}, i, int) \times D_0(t_{meas}, i)$$

where: $f(t_{meas},\ i,\ int)$ is a function that represents the variation of ^{131}I in the thyroid before and after the measurement; this function depends on t_{meas}, on the age of the individual *i*, and on the mode *int* of ^{131}I intake (cf. Figure 4). Only inhaltion during cloud passage and ingestion of fresh milk were considered as intakes *int*.

Figure 4: Example of ^{131}I activity dynamics in thyroid gland



In the databases, if the "rate" was equal to zero, or if background was greater than or equal to the signal, then inhalation doses were assigned for thyroid doses according to the following procedure for each individual in that case [Shinkarev, 1999]:

1. Average dose was calculated for adults with nonzero thyroid dose in a settlement,
2. In rural settlement, it was assumed that the ratio of ingestion intake of ^{131}I to inhalation of ^{131}I was equal to 20 for adults who stayed all the time and consumed fresh milk locally produced without stop. Correction factors were

introduced to take into account personal data of the individual considered, and a "new dose", fitting these characteristics, was calculated,

3. 1/20th of the "new dose" was considered to be the estimate of inhalation dose for an adult,
4. Inhalation doses for children were calculated on the basis of inhalation doses for adults, after introducing correction factors according to the children's age to take into account different inhalation dose factors and breathing rates.

2.4. Methodology of analysis of the initial thyroid dose estimates

Our purpose is to develop an index that would help us to analyze data on doses obtained by population of Belarus. This index has to be robust enough to be used for wide variety of external conditions, as different settlements and kind of depositions. The settlements in Narovlya district received different levels and kind of fallout according to their exact location: from 37 to more than 1,480 kBq.m^{-2} of ^{137}Cs [Germenchuk, 2000]. The thyroid doses depend primarily on ^{131}I fallout, for which few data were available. Thyroid doses are proportional to the ^{137}Cs or the ^{131}I deposition, but the proportion coefficients are likely to vary according to the type of deposition (dry, wet, or combination) [Gavrilin 1999].

On the other hand it has to be sensitive to age, sex, habits, etc, of people included in the study. ^{131}I could be inhaled during the passage of the plume or could be ingested with food products, and especially fresh milk. Thyroid doses are also age-dependent: the effects of the same level of activity are more dangerous when the size of the thyroid gland is small, as for infants or young children.

As we are interested in damage to the thyroid gland by radiation the universal measure of the damage will be energy released by radioactive iodine in the thyroid. With the help of known estimation of doses to thyroid, the total energy (J) received by an individual i aged j can be assessed as a product of the measure dose d_{meas} (Gy, i.e. J.kg^{-1}) by thyroid mass tm (kg):

$$energy\ (i, j) = d_{meas}(i, j) \times tm(j)$$

where: $d_{meas}(i, j)$ is the value of estimated thyroid dose for an individual i, j years old in 1986 (based on year of birth),
$tm(j)$ is the thyroid mass, assessed according to the age j of the person in 1986.

The age j was based on the year of birth only, e.g. 6 year old means here that the individual was born in 1980. The thyroid mass values were based on ICRP 56 data [ICRP, 1989] (cf. Table A2 in Annexes).

To exclude from our index influence of the deposition level and the kind of deposition, we divided the thyroid dose d_{meas} by the geometric mean of thyroid doses assessed for adults in every settlement S where 10 or more adults were subjected to thyroid direct measurements ($GM(d_{meas}(ad, S))$, cf. Table A4 in Annexes). In order to obtain a number dimensionless, we also divided d_{meas} by the thyroid mass for adults *tm(ad)* (i.e. 20 g). Thus, we calculated a dimensionless dose index (*DI*) for each individual *i* from the settlement *S* and age *j* according to the following formula:

$$DI(i, j, S) = (d_{meas}(i, j) \times tm(j)) / (GM(d_{meas}(ad, S)) \times tm(ad))$$

where: $d_{meas}(i, j)$ is the value of estimated thyroid dose for an individual *i*, *j* years old in 1986 (based on year of birth) (in Gy),
tm(j) is the thyroid mass, assessed according to the age *j* of the person in 1986 (in g),
tm(ad) is the thyroid mass for adults, i.e. 20 g,
$GM(d_{meas}(ad, S))$ is the thyroid doses geometric mean for 10 or more adults from the settlement *S* (in Gy).

We considered the milk consumption as a constant parameter for the time being.

3. Results

3.1 Preliminary analysis

3.1.1. Available information per field in Narovlya district and Minsk city databases

We disposed from the following information about the 12,705 people from Narovlya district kept in our study:

- Personal data: individual code, district, settlement, and year of birth were recorded for these 12,705 people. Profession was available for 4,545, and concerned workers as well as students or scholar children or retired people. Furthermore, we added previously the field "gender" for 4,454 males and 5,130 females,
- Evacuation data: the date when the person left the settlement was recorded for everyone, but in 9,454 of the cases, the date was not given during the 1988 interviews but assigned by people who computerized the data, as the most probable date of evacuation for the settlement where the person lived,
- Milk data: the date when cows began to consume pasture grass was recorded for everyone, but was assigned in 10,317 cases by people who computerized the data, as the most probable date. 3,571 people gave their daily fresh milk consumption, and 2,693 the date when they stopped consuming fresh milk (between 15 April 1986 and 15 July 1986),
- Iodine prophylaxis data: the date when the person started taking potassium-iodide pills was recorded for 2,314 people, but some dates were unlikely well recorded, and 1,275 people (not necessarily included in the 2,314 previous ones)

said they took KI pills at least once. This very confusing information led us not to analyze data concerning iodine prophylaxis effects on the thyroid doses,

- Recorded data from direct thyroid measurement: date and "rate" were recorded for everybody, the measure rate (i.e. before correction) in only 7,311 cases, and the IDIndex device in 10,634 cases. A field called "sign" was filled in for 254 people with the sign "<", which meant, "the actual exposure rate against thyroid was lower than written in the field measure rate" [Shinkarev, 1999]. We didn't use this last information,
- "Dose" was available for all people kept in our study.

For every person among the 17,819 people from Minsk city kept in our study we disposed of year of birth, region and city where they lived, a detailed address in 3,906 cases, and gender in 9,380 cases. The information on direct thyroid measurement consisted in the date of measurement, the IDIndex device used, the "rate" and the estimated dose for everyone of them. Milk consumption was recorded for 1,878 children belonging simultaneously to the Belarussian-American study cohort.

3.1.2 Bias linked to the IDIndex

Initially we calculated GM and GSD of *DI* for each IDIndex device with which more than 100 measurements were conducted in Narovlya district (cf. Table 3).

Table 3: GM and GSD of *DI* for people from Narovlya district per IDIndex device

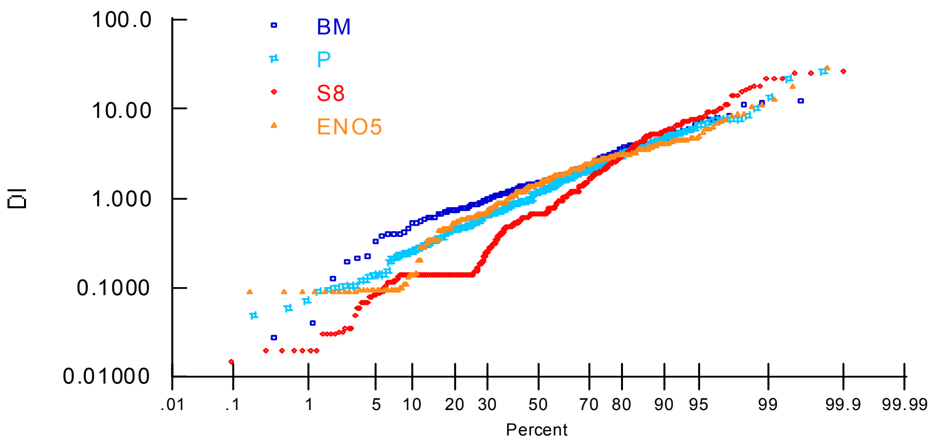
Characteristics of the measurements			# of people	GM(DI)	GSD(DI)
IDIndex	**Device**	**Place**			
F	unknown	Paramedic-obstetrician office	1,596	1.06	2.64
EF5	DP5	Paramedic-obstetrician office (Data with restored date)	426	1.17	2.76
EP5	DP5		632	1.29	3.46
P5	DP5	Summer camp, rest house, sanatorium, etc.	376	0.88	4.30
P	unknown		266	1.11	3.11
V5	DP5	Measurements made by military	641	0.94	3.12
S8	SRP-68-01	General lists of inhabitants[1]	534	0.70	4.61
O	unknown		256	0.98	2.50
ENO5	DP5	Narovlyanskiy district General lists of inhabitants[1] (Data with restored date)	304	1.18	3.26
ENAR5	DP5	Narovlyanskiy district (Data with restored date)	107	1.23	2.84
NR8	SRP-68-01	Narovlya district	852	0.89	3.38
NR5	DP5		1,356	1.15	3.04
NR	unknown		589	1.11	3.04
GMR5	DP5	Mozyr district (Gomel region)[2]	284	0.69	4.60
GMR	unknown		242	0.47	4.21
P28M8	SRP-68-01	Polyclinic 28 in Minsk[2]	529	0.98	3.78
BM	unknown	Hospital in Minsk[2]	134	1.47	2.70

Measurements done in same kind of places and sometimes with same devices showed large variation according to the IDIndex. So we suspected that the IDIndex device, i.e. the combination of the place of measurement and the kind of device used for the measure, was an origin of bias in the model used for thyroid dose assessment. The plot of *DI* distributions according to the IDIndex device showed a large variation (cf. Figure 5).

[1] General lists of inhabitants: inhabitants with results of measurements on different dates

[2] People who were subjected to measurement in Minsk or Mozyr districts, but were adults and children arriving from Narovlya town, evacuated villages and nonevacuated villages from Narovlya district.

Figure 5: DI distribution for people from Narvolya district, according to the IDIndex device used for measurement

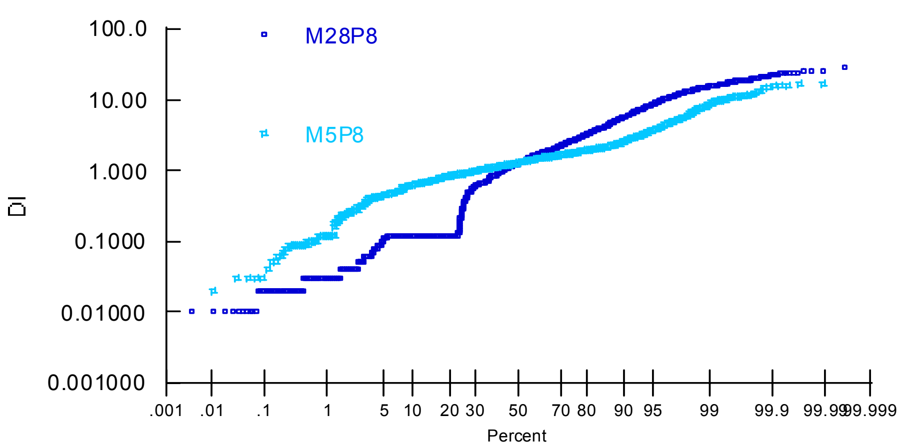


Only two IDIndex devices were used to perform measurements on people who stayed in Minsk at the time and after the accident:

- 74 % with M28P8, i.e. 13,135 people who were subjected to a direct thyroid measurement in the Polyclinic # 28 in Minsk city with an SRP-68-01 device.
  GM(*DI*) = 0.94 for that category (GSD(*DI*) = 4.52),
- 26 % with M5P8, i.e. 4,684 people who were subjected to a direct thyroid measurement in the Polyclinic # 5 in Minsk city with an SRP-68-01 device.
  GM(*DI*) = 1.26 for that category (GSD(*DI*) = 1.97).

The bias linked to the IDIndex seemed to be present here too (cf. Figure 6).

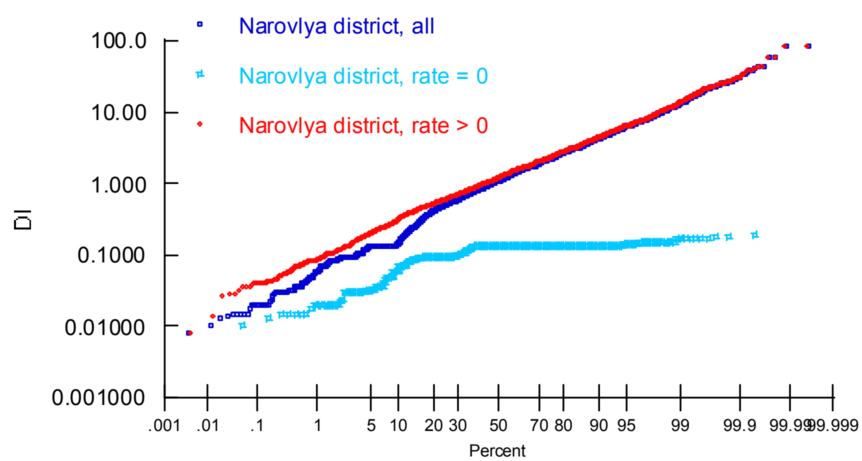
Figure 6: DI distribution for people from Minsk city, according to the IDIndex device used for measurement

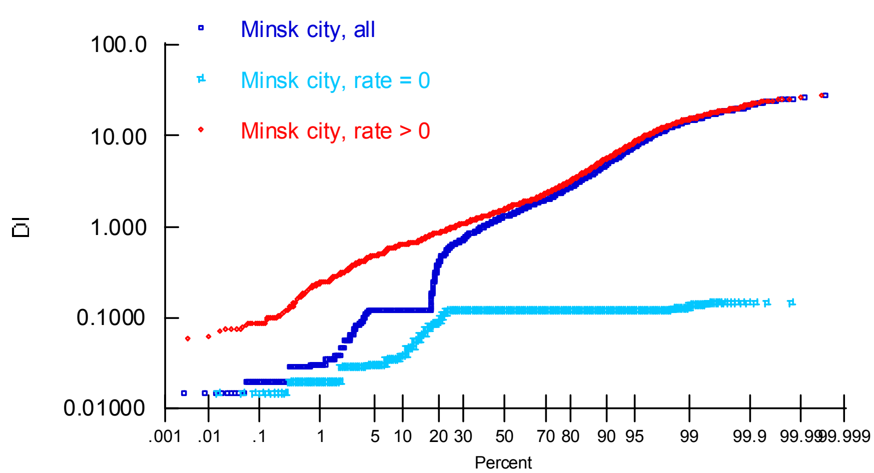


3.1.3. Numerous zeros recorded for the "rate" value

Another source of substantial differences were data with a zero as value for exposure rate ("rate"). Measure of the individual and of the background took place in various conditions, which complicated to take into account environmental pollutions. Background level could have been overestimated and then a value zero was recorded as rate. Thus the plot of DI distributions according to the value of the field "rate", equal or higher than 0, showed a large variation (cf. Figure 7). The value of zero was recorded for 920 people from Narovlya district (7 %) and 3,127 people from Minsk city (18 %); it seemed to be the origin of plateaus in the distributions.

Figure 7: DI distributions for people from Narovlya district and from Minsk city, according to their rate





Therefore we preferred not to consider people with a recorded “rate” equal to zero. Only the subset of the databases excluding people with “zeros” values for “rate”, will be used for further analysis, which will introduce a new dose index corrected for the IDIndex device.

3.1.4. Correction of the bias due to “IDIndex” for the subset of databases

In a first step, we excluded all the individuals, either adults or children, with a “rate” equal to zero from Narovlya district and Minsk city databases. Then, the dose index for this subset of people with a “rate” greater than zero, $DI_{>0}$ (dimensionless), became:

$$DI_{>0}(i, j, S) = (d_{meas}(i_{with\ rate>0}, j) \times tm(j)) / (GM(d_{meas}(ad_{with\ rate>0}, S)) \times tm(ad))$$

where: $d_{meas}(i_{with\ rate>0}, j)$ is the value of estimated thyroid dose for the individual i, aged j in 1986 (based on year of birth), and whose recorded “rate” is higher than 0 (in Gy),

$tm(j)$ is the thyroid mass, as a function of age j of the person in 1986 (in g),

$tm(ad)$ is the thyroid mass for adults, i.e. 20 g,

$GM(d_{meas}(ad_{with\ rate>0}, S))$ is the thyroid doses geometric mean for 10 or more adults from the settlement S and whose recorded “rate” are higher than 0 (in Gy).

7 % of the adults from Narovlya district database were excluded by this way, as well as 8 % of the newborns, 9 % of the children aged 1 to 2, 6 % of the children aged 3 to 7, 5 % of the children aged 8 to 12 and 12 % of the teenagers aged 13 to 18. For Minsk city database, we excluded 20 % of the adults, 16 % of the newborns, 12 % of each category 1 to 2, 3 to 7, 8 to 12 years old, and 13 % of the teenagers aged 13 to 18.

In a second step, we assessed GM of $DI_{>0}$ per IDIndex categories including more than 10 people, adults and children considered together, and we proposed a new dose index, $DIc_{>0}$, corrected for the IDIndex device (dimensionless):

$$DIc_{>0}(i, j, S, k) = DI_{>0}(i, j, S) / GM(DI_{>0}(k))$$

where: $GM(DI_{>0}(k))$ is the DI geometric mean for people, adults and children considered together, who were measured with the IDIndex device k and whose recorded “rate” are higher than 0 (dimensionless). $GM(DI_{>0}(k))$ was calculated if more than 10 measurements were recorded for the IDIndex device k, without any age consideration (cf. Table A3 in Annexes).

3.2. Analysis of the data for Narovlya district

We studied the three sub-databases together (Narovlya district, cf. Tables 4 and 5) and separately (evacuated villages, cf. Table 6, nonevacuated villages, cf. Table 7, and Narovlya town, cf. Table 8).

Table 4: GM and GSD of $DIc_{>0}$ for people from Narovlya district per age

Category	# of people	GM	GSD
all	11,549	1.00	2.79
adults	8,903	0.99	2.73
> 50 years	3,930	1.03	2.66
31 years – 50 years	3,082	0.93	2.71
19 years – 30 years	1,891	1.01	2.90
children	2,646	1.03	2.97
0 year	50	0.40	3.05
1 year – 2 years	301	0.90	3.17
3 years – 7 years	846	0.91	2.89
8 years – 12 years	657	1.12	2.86
13 years – 18 years	792	1.23	2.90

For adults small difference could be seen between the different age categories. GM for all children was equal to 1.03, but a more detailed study per age showed that GM was rising with age from a very low level for newborns (0.40) to 1.23 for children between 13 and 18 years old. However GSD was quite large, especially for young children, which meant that this group was heterogeneous (cf. Figures 8 and 9).

Figure 8: GM of $DIc_{>0}$, for people from Narovlya district, according to their age

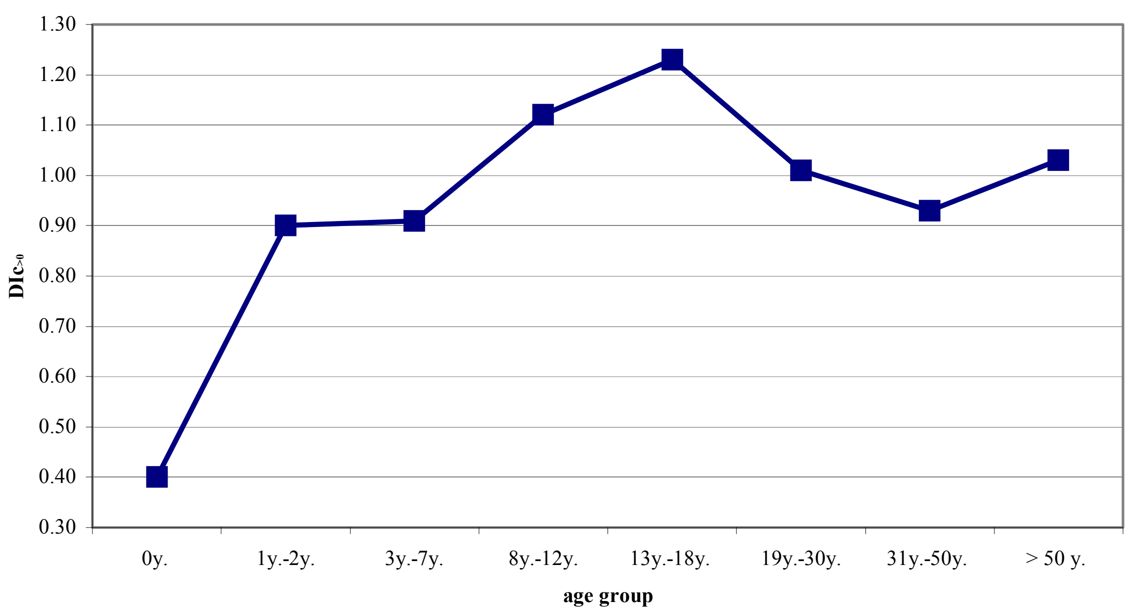
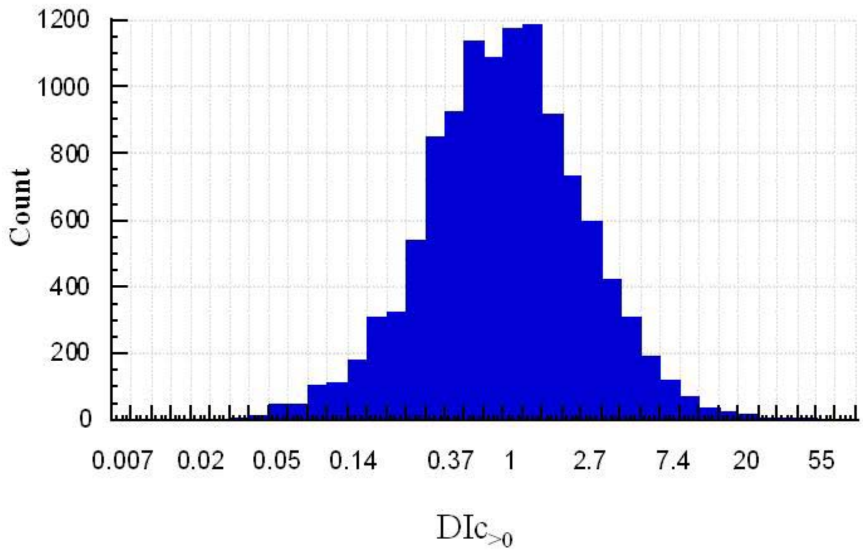
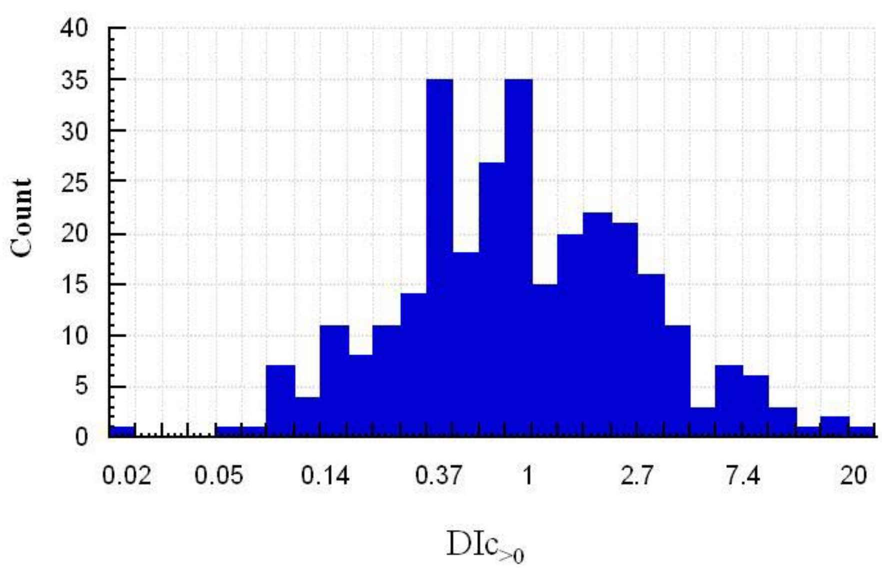


Figure 9: Distribution of $DIc_{>0}$ people from Narovlya district on a logarithmic scale



This variability is particularly important for children aged from 1 to 2 years (cf. Figure 10). At least a factor 100 could be observed between the 6 lowest and the 6 highest values of $DIc_{>0}$.

Figure 10: Distribution of $DIc_{>0}$ for children aged 1 to 2, Narovlya district, on a logarithmic scale



We assessed GM and GSD of $DIc_{>0}$ for people from Narovlya district according to their age and gender, when gender information were available (cf. Table 5). Male adults had higher GM than female adults, as boys comparing to girls. We calculated a new corrected dose index, considering separately males and females, $DIc_{>0,\ per\ gender}$, according to the following formulas (dimensionless):

$$DI_{>0,\ per\ gender}(i, g, j, S) = (d_{meas}(i_{with\ rate>0,\ gender\ g}, j) \times tm(j)) \\ / (GM(d_{meas}(ad_{with\ rate>0,\ gender\ g}, S)) \times tm(ad))$$

where: $d_{meas}(i_{with\ rate>0,\ gender\ g}, j)$ is the value of thyroid dose for the individual *i*, aged *j* in 1986 (based on year of birth), whose gender *g* is known, and whose recorded "rate" is higher than 0 (in Gy),
$tm(j)$ is the thyroid mass, as a function of age *j* of the person in 1986 (in g),
$tm(ad)$ is the thyroid mass for adults, i.e. 20 g,
$GM(d_{meas}(ad_{with\ rate>0,\ gender\ g}, S))$ is the thyroid doses geometric mean for adults of same gender *g*, from the settlement *S* and whose recorded "rate" are higher than 0 (in Gy).

and :

$$DIc_{>0,\ per\ gender}(i, g, j, S, k) = DI_{>0,\ per\ gender}(i, g, j, S) / GM(DI_{>0,\ per\ gender}(k, g))$$

where: $GM(DI_{>0,\ per\ gender}(k, g))$ is the *DI* geometric mean for people of gender *g*, adults and children considered together, who were measured with the IDIndex device *k* and whose recorded "rate" are higher than 0 (dimensionless). $GM(DI_{>0,\ per\ gender}(k))$ was calculated if more than 10 measurements were recorded for the device *k* for people of gender *g*, without any age consideration.

Because we calculated $GM(DI_{>0,\ per\ gender}(k, g))$ in each category when at least 10 measurements with the same IDIndex device for people of the same gender were available, the number of people for whom we were able to assess a $DIc_{>0,\ per\ gender}$ could be slightly smaller from the number of people for whom we assessed $DIc_{>0}$, where $GM(DI_{>0}(k))$ didn't take into account the gender.

Table 5: GM and GSD of $DIc_{>0}$ for people from Narovlya district per age and gender

Category	$DIc_{>0}$			$DIc_{>0,\ per\ gender}$		
	# of people	GM	GSD	# of people	GM	GSD
adults, men	2,999	1.00	2.65	2,919	0.98	2.62
adults, women	3,716	0.95	2.68	3,671	0.99	2.66
children, boys	1,103	1.13	3.05	1,071	1.07	3.02
0 year, boys	14	0.50	3.83	14	0.48	3.41
1 year – 2 years, boys	145	0.90	3.39	141	0.85	3.27
3 years – 7 years, boys	358	0.96	2.91	352	0.90	2.85
8 years – 12 years, boys	265	1.31	2.88	259	1.21	2.87
13 years – 18 years, boys	321	1.39	3.00	305	1.35	3.00
children, girls	1,004	0.97	2.75	985	1.05	2.75
0 year, girls	23	0.39	3.01	22	0.39	2.77
1 year – 2 years, girls	107	0.94	2.83	104	1.02	2.80
3 years – 7 years, girls	329	0.92	2.73	324	1.00	2.73
8 years – 12 years, girls	292	1.04	2.72	288	1.13	2.76
13 years – 18 years, girls	253	1.06	2.64	247	1.12	2.63

The new formulas, per gender, conducted to decrease the difference of the corrected dose index between females and males for adults. But the function of $DIc_{>0,\ per\ gender}$ according to the age was flatter for girls, on the contrary to the function for boys which presented an increase between 0 year old 18 year old, and higher values of GSD. Different assumptions could be considered to explain this variation, as difference in daily milk consumption (cf. part 4.2.), in thyroid uptake fraction, in thyroid size, or others (devices, date and place of measurement...).

Results per age category for people from evacuated villages only were quite different, since GM values for adults, children aged 0 to 2 and teenagers aged 13 to 18 only were higher than 1 (cf. Table 6). For young children aged 0 to 7, the high values of GSD could certainly be linked to the milk consumption.

Table 6: GM and GSD of $DIc_{>0}$ for people from evacuated villages in Narovlya district

Category	# of people	GM	GSD
all	945	1.01	2.81
adults	821	1.01	2.77
children	124	1.02	3.09
0 year – 2 years	11	1.26	4.78
3 years – 7 years	33	0.76	3.35
8 years – 12 years	27	0.90	2.73
13 years – 18 years	53	1.26	2.71

There were only 11 children aged 0 to 2 from evacuated villages in the Narovlya district database, but at least a factor 100 was observed between the lowest and the highest value of

$DIc_{>0}$ ($DIc_{>0}$ = 0.08 to 9.01). No real discrepancy was observed in the personal data for all these people to explain such high variation.

Results for people from nonevacuated villages were different from those from evacuated villages (cf. Table 7): GM values were almost equal to 1 for adults, higher for children, but starting from 0.37 for newborns and ending with 1.27 for teenagers.

Table 7: GM and GSD of $DIc_{>0}$ for people from nonevacuated villages in Narovlya district

Category	# of people	GM	GSD
all	6,058	0.99	2.78
adults	4,924	0.98	2.72
children	1,134	1.06	3.06
0 year	21	0.37	3.66
1 year – 2 years	117	0.82	3.24
3 years – 7 years	289	0.94	3.03
8 years – 12 years	293	1.10	3.00
13 years – 18 years	414	1.27	2.89

Results for Narovlya town were comparable to those for nonevacuated villages (cf. Table 8).

Table 8: GM and GSD of $DIc_{>0}$ for people from Narovlya town

Category	# of people	GM	GSD
all	4,546	1.01	2.79
adults	3,158	1.01	2.74
children	1,388	1.01	2.88
0 year	27	0.45	2.62
1 year – 2 years	175	0.92	3.06
3 years – 7 years	524	0.91	2.79
8 years – 12 years	337	1.17	2.75
13 years – 18 years	325	1.18	2.94

3.3. Analysis of the data for Minsk city

We assessed GM and GSD of $DI_{>0}$ for people from Minsk city according to their age (cf. Table 9).

Table 9: GM and GSD of $DIc_{>0}$ for people from Minsk city

Category	# of people	GM	GSD
all	14,692	1.00	2.33
adults	9,135	1.04	2.26
> 50 years	1,764	0.91	2.03
31 years – 50 years	4,498	1.00	2.24
19 years – 30 years	2,873	1.20	2.40
children	5,557	0.94	2.42
0 year	54	0.44	2.68
1 year – 2 years	871	0.86	2.72
3 years – 7 years	2,365	0.92	2.50
8 years – 12 years	1,440	0.97	2.20
13 years – 18 years	827	1.07	2.16

These results showed differences between GM for different groups of age, even for adults, but values of GSD of $DIc_{>0}$ for people from Minsk city were smaller than those for people from Narovlya district. More individuals were removed from Minsk city database because of their "rate" equal to zero. The people left for the study constituted a more homogeneous group (cf. Figures 11 and 12). Results for children showed that GM was rising with age.

Figure 11: GM of *$DIc_{>0}$*, for people from Minsk city, according to their age

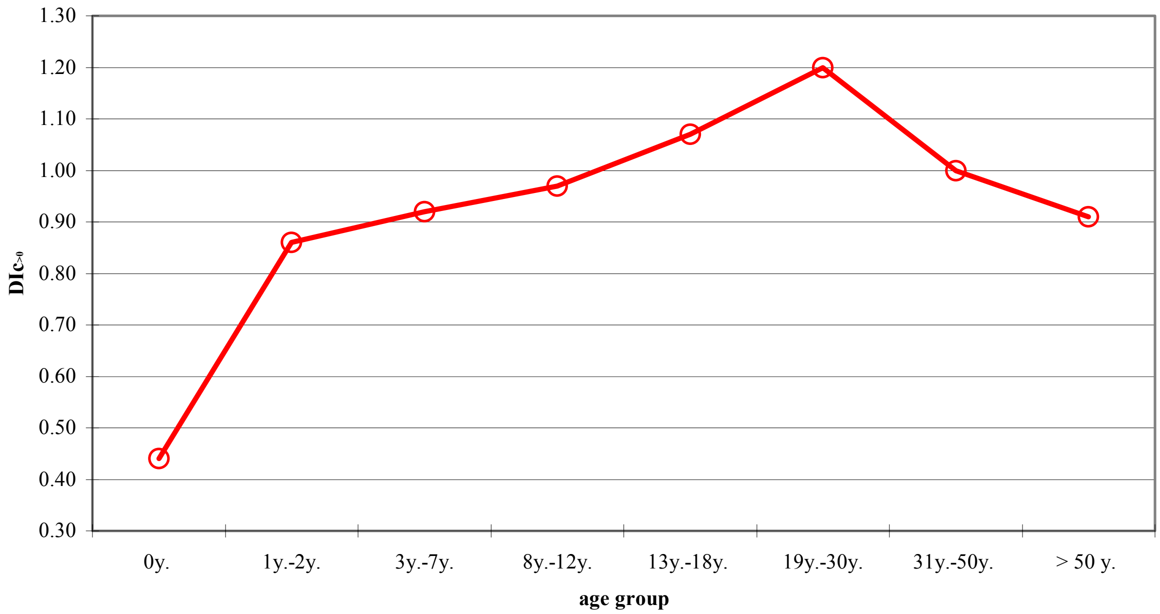
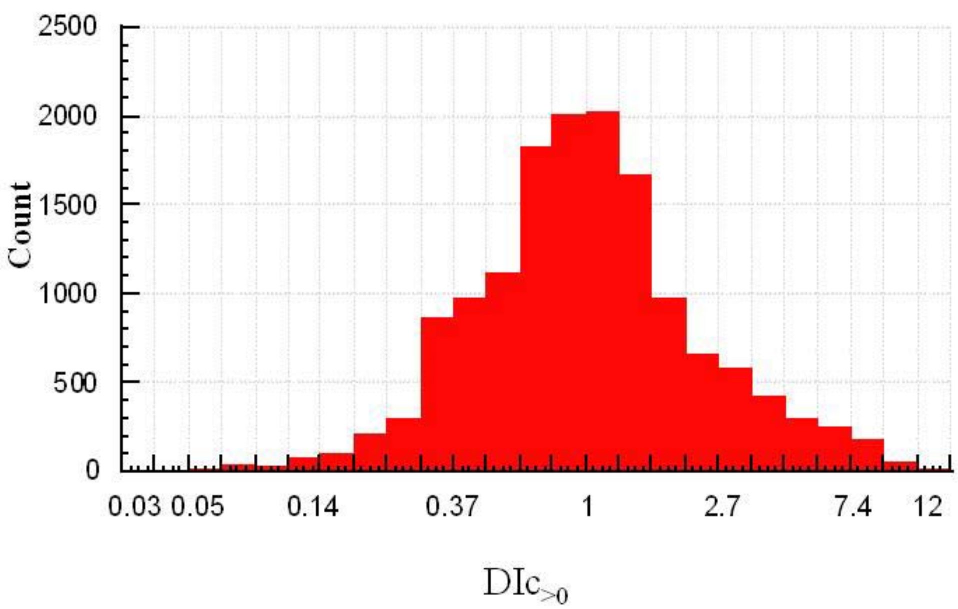
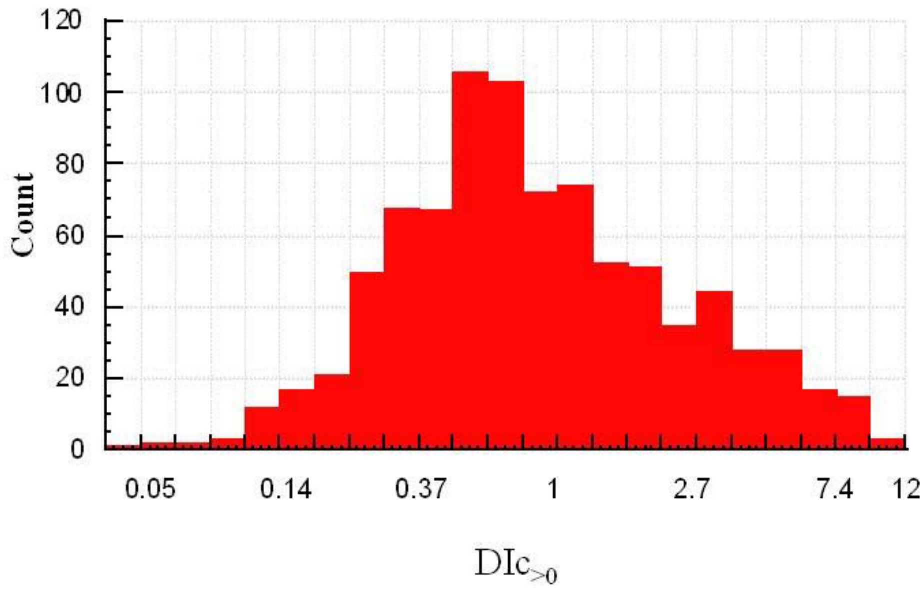


Figure 12: Distribution of *$DIc_{>0}$* for people from Minsk city on a logarithmic scale



Higher GSD values were found for small age groups, which showed a large heterogeneity in these categories. A factor of about 50 could be observed between the lowest and the highest values of $DIc_{>0}$ for the 54 children aged 0 ($DIc_{>0}$ = 0.06 to 2.90), perhaps because of the few number of people in that category. But a factor of about 230 could be observed between the lowest and the highest values of $DIc_{>0}$ for children aged 1 to 2, more numerous ($DIc_{>0}$ = 0.05 to 11.66) (cf. Figure 13).

Figure 13: Distribution of $DIc_{>0}$ for children aged 1 to 2, Minsk city, on a logarithmic scale



We assessed GM and GSD of $DIc_{>0}$ for people from Minsk city according to their age and gender (cf. Table 10). The difference between GM of $DIc_{>0}$ for men and women led us to calculate $DIc_{>0,\ per\ gender}$ as previously done for people from Narovlya district. As for Narovlya district's calculations, number of people in each category could be slightly smaller for $DIc_{>0,\ per\ gender}$ assessments than for $DIc_{>0}$ assessment, because of the rules to estimate $GM(DI_{>0}\ (k))$ and $GM(DI_{>0,\ per\ gender}(k, g))$.

Table 10: GM and GSD of $DIc_{>0}$ for people from Minsk city per age and gender (information on gender was not available for some people)

Category	$DIc_{>0}$			$DIc_{>0, per\ gender}$		
	# of people	GM	GSD	# of people	GM	GSD
adults, men	1,468	1.04	2.23	1,468	1.08	2.20
adults, women	2,933	0.86	2.17	2,933	1.02	2.13
children, boys	1,723	0.88	2.47	1,723	0.93	2.41
0 year, boys	14	0.31	2.31	14	0.26	2.29
1 year – 2 years, boys	246	0.63	2.84	246	0.77	2.75
3 years – 7 years, boys	771	0.87	2.51	771	0.91	2.43
8 years – 12 years, boys	447	0.94	2.26	447	0.98	2.20
13 years – 18 years, boys	245	1.02	2.19	245	1.15	2.17
children, girls	1,797	0.85	2.46	1,797	0.98	2.41
0 year, girls	20	0.51	3.03	20	0.67	2.93
1 year – 2 years, girls	254	0.65	2.64	254	0.82	2.55
3 years – 7 years, girls	752	0.82	2.58	752	0.98	2.53
8 years – 12 years, girls	503	0.93	2.27	503	1.05	2.23
13 years – 18 years, girls	268	0.94	2.19	268	1.07	2.17

The variation of results per gender was narrower in Minsk city's case than in Narovlya district's case. The use of formulas per gender conducted to a smoother decrease the difference of the corrected dose index between females and males for adults. But as previously seen for people of Narovlya district, the function of $DIc_{>0, per\ gender}$ according to the age was flatter for girls, on the contrary to the function for boys which presented a increase between 0 year old 18 year old, and higher values of GSD.

Results obtained for people from Minsk city were quite similar to those obtained for people from Narovlya district, except for the gender effect for adults (cf. Figures 14 and 15). Results for evacuated people from Narovlya district seemed apart, especially for children aged 0 to 2, but very few people entered in that category.

Figure 14: GM of $DIc_{>0}$ for people from Narovlya district and Minsk city, per age and per settlement

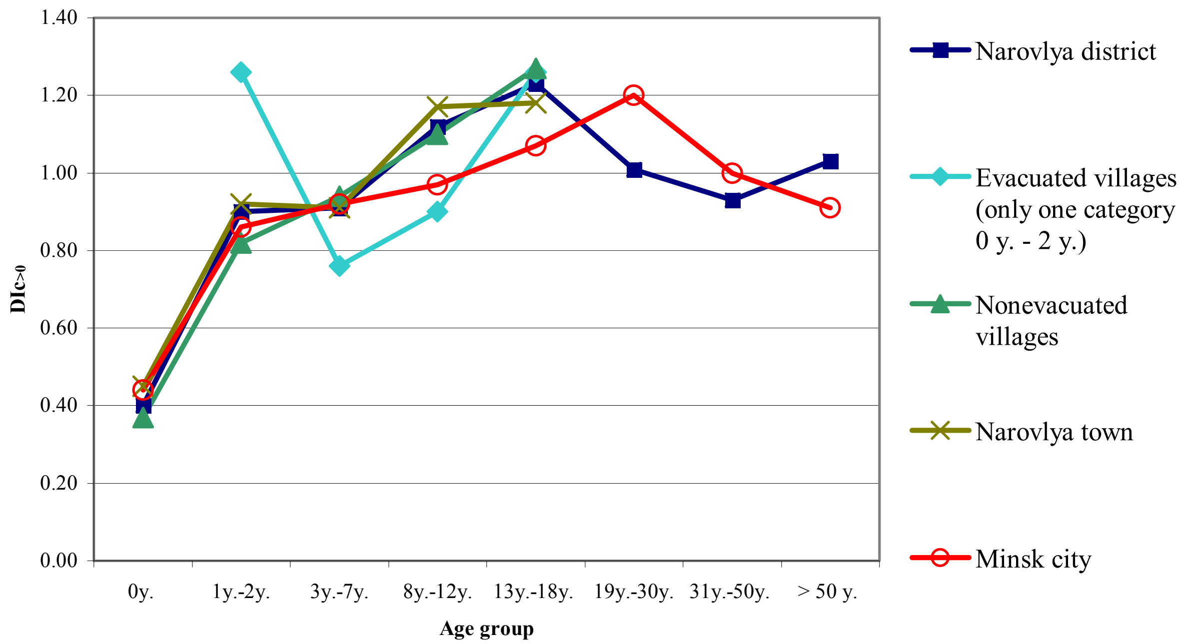
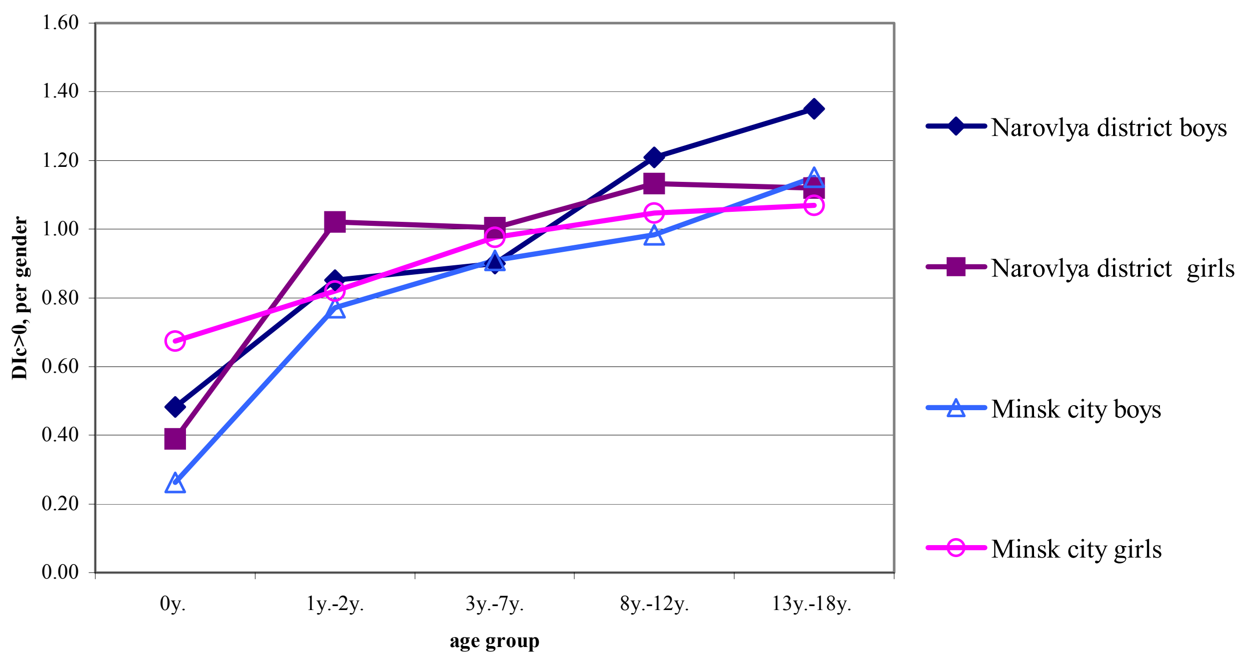


Figure 15: GM of $DIc_{>0, \text{per gender}}$ for children from Narovlya district and Minsk city, per age and per gender



4. Discussion

4.1. Age effect

An effect of the age could be seen in the results. In Narovlya district, GM of $DIc_{>0}$ stayed lower than 1 for children aged 0 to 7. In evacuated villages, categories between 3 and 12 years old were in that case, all categories between 0 and 7 years old in nonevacuated villages and in Narovlya town. For people from Minsk city, categories with a GM of $DIc_{>0}$ lower than 1 were concerning people older than 31 or younger than 12.

Two age effects could be considered: the size of thyroid gland and the milk consumption. The first one was taken into account since thyroid volumes were one of the parameters used to define $DIc_{>0}$. But a bias induced by calibration factors for the different devices according to the gland size should not be excluded, especially for young children.

We looked into the results in regard to milk data. In Narovlya district database the daily consumption of milk was recorded for some people during 1988 interviews. We took into account only those with $DIc_{>0}$, i.e. 294 people from evacuated and primarily 3,119 people from nonevacuated villages. Milk data were not available for inhabitants from Narovlya town. Thus, these data were more representative of a rural area (cf. Table 11). For Minsk city, data on milk consumption were available only for children included in the Belarussian-American cohort. 1,701 Minsk city inhabitants for whom we were able to calculate $DIc_{>0}$ belong to this cohort.

Table 11: Daily consumption of fresh milk for people from villages included in Narovlya district and for children from Minsk city, per age categories ($L.d^{-1}$)

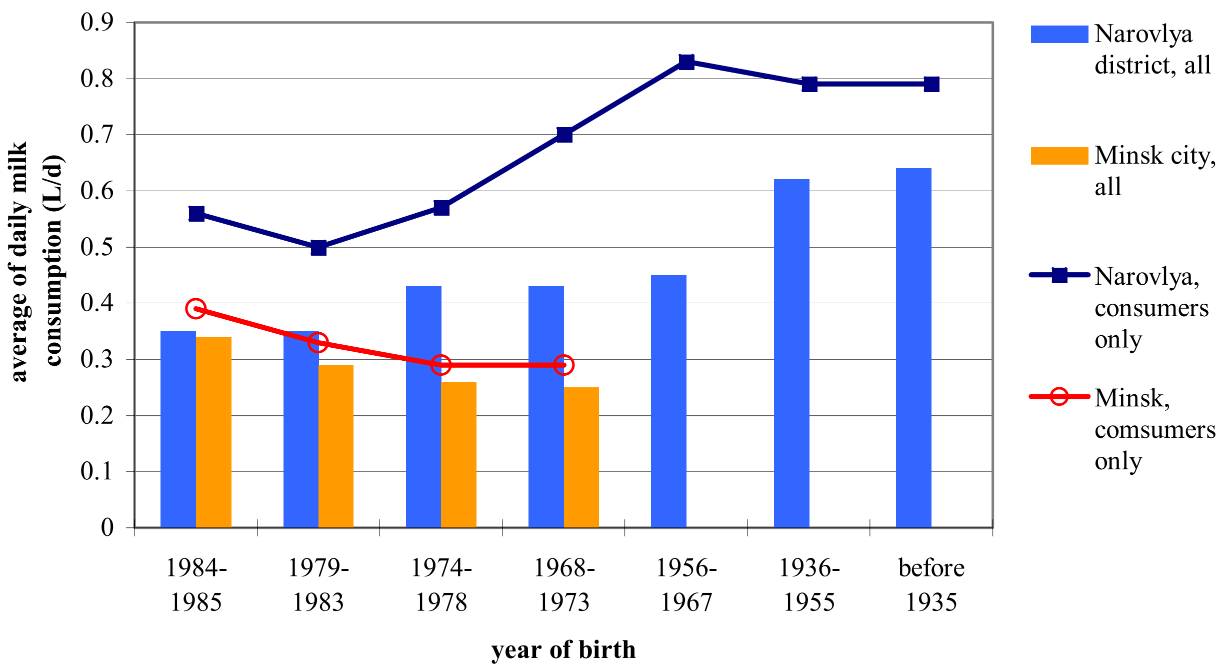
Category	# of people	% of non-consumers	Median ($L.d^{-1}$)		Average ($L.d^{-1}$)		Standard deviation ($L.d^{-1}$)
			for all	for consumers	for all	for consumers	for consumers
People from villages included in Narovlya district							
<u>adults</u>	2,796	22	0.50	0.60	0.61	0.79	0.40
> 50 years	1,590	18	0.50	0.50	0.64	0.79	0.41
31 years – 50 years	882	22	0.50	0.60	0.62	0.79	0.39
19 years – 30 years	324	46	0.50	0.80	0.45	0.83	0.39
<u>children</u>	617	33	0.40	0.50	0.39	0.58	0.32
1 year – 2 years	66	38	0.40	0.50	0.35	0.56	0.27
3 years – 7 years	176	30	0.40	0.50	0.35	0.50	0.23
8 years – 12 years	184	24	0.50	0.50	0.43	0.57	0.25
13 years – 18 years	179	39	0.40	0.50	0.43	0.70	0.44

Table 11(continued): Daily consumption of fresh milk for people from villages included in Narovlya district and for children from Minsk city, per age categories ($L.d^{-1}$)

Category	# of people	% of non-consumers	Median ($L.d^{-1}$)		Average ($L.d^{-1}$)		Standard deviation ($L.d^{-1}$)
			for all	for consumers	for all	for consumers	for consumers
People from villages included in Minsk city							
children	1,701	12	0.20	0.22	0.28	0.32	0.29
1 year – 2 years	187	12	0.30	0.30	0.34	0.39	0.28
3 years – 7 years	764	11	0.20	0.25	0.29	0.33	0.28
8 years – 12 years	478	10	0.14	0.20	0.26	0.29	0.29
13 years – 18 years	264	15	0.13	0.20	0.25	0.29	0.33

As shown in Figure 16, data on fresh milk consumption is a rising function of age with plateaus for people from Narovlya district. For Minsk city, the function presented the opposite tendency. In both cases, children who were breastfed had not their milk consumption recorded.

Figure 16: Average of daily milk consumption ($L.d^{-1}$) according to the 1988 interviews for people from Narovlya district and to the BelAm study for children from Minsk city (people with direct thyroid measurement)



In villages from Narovlya district, the daily milk consumption was different for adults and for children: adults drank a higher quantity of milk than children. Firstly milk could be drunk instead of water in this rural area; secondly breastfeeding was a common habit.

Therefore 0-year-old children, i.e. born between January and April 1986, were not likely to drink milk from cows or goats. Young children drank less than teenagers, and so daily milk consumption of milk was higher for teenagers, in the same order than for adults. Results could be not necessarily very representative when we considered children per age, because of the small number of people in each category.

These different variations in daily consumption of milk could explain why the GM of $DIc_{>0}$ was smaller than 1 for children from aged 0 to 7 (3 to 12 for children from evacuated villages), higher for children aged 8 to 12 from nonevacuated villages (and Narovlya town), but not the even higher values of GM of $DIc_{>0}$ for teenagers aged 13 to 18. For newborns, data on breastfeeding were not recorded, and two opposite tendencies were observed: $DIc_{>0}$ higher than 1 in evacuated villages and lower than 1 in nonevacuated villages and town.

Problems of representative sample with regard to dietary habits and to number of interviewed people led us to test the effect of milk consumption considering all these people together (cf. Table 12).

Table 12: GM and GSD of $DIc_{>0}$ for people from villages included in Narovlya district who gave their daily milk consumption when they were interviewed in 1988

Category	# of people	GM	GSD
0 $L.d^{-1}$	832	0.87	2.71
> 0 $L.d^{-1}$ - ≤ 0.5 $L.d^{-1}$	1,382	0.97	2.65
> 0.5 $L.d^{-1}$ - ≤ 1 $L.d^{-1}$	1,001	1.06	2.66
> 1 $L.d^{-1}$ - ≤ 1.5 $L.d^{-1}$	108	1.25	2.66
> 1.5 $L.d^{-1}$ - ≤ 2 $L.d^{-1}$	78	1.16	2.47

These results showed that GM of $DIc_{>0}$ rose gradually with the increase of daily quantity of milk consumption and stayed below 1 for people who didn't drink fresh milk. Differences of daily milk consumption were taken into account by the model of thyroid dose calculation. However the increase was quite smooth and especially the value for high milk consumption seemed too low, perhaps due to very low number of people in these categories, and led us to question the actual reliability of the answers about milk consumption rates. Information on leafy vegetables consumption would complete useful data on milk intake, as one of the primarily pathway for ^{131}I from the environment to the thyroid gland, but were not recorded during the 1988 interview round.

Milk consumption in Minsk city was very different from the one observed in Narovlya district, and showed the characteristics of milk consumption in urban area: newborns were less breastfed and younger children consumed more milk than teenagers. This didn't explain the results obtained for GM of $DIc_{>0}$, for which the increase was going in the opposite direction.

4.2. Gender effect

Because no data about thyroid mass per age and per gender were available, we didn't consider any variation of *tm(a)* according to the sex. Results of GM calculation for $DIc_{>0}$ and $DIc_{>0,\ per\ gender}$ showed that for Narovlya district, men and women were in the same range of values. But this variation could be seen for boys and girls. Thus we checked if milk consumption was different according to the gender (cf. Table 13).

Table 13: Daily consumption of fresh milk for people from villages included in Narovlya district, per age and gender categories ($L.d^{-1}$)

Category	# of people	% of non-consum-ers	Median ($L.d^{-1}$)		Average ($L.d^{-1}$)		Standard deviation ($L.d^{-1}$)
			for all	for consumers	for all	for consumers	for consumers
adults, men	1,145	23	0.50	0.80	0.64	0.83	0.41
adults, women	1,532	18	0.50	0.50	0.63	0.77	0.39
1 year – 2 years, boys	36	42	0.40	0.50	0.37	0.63	0.31
3 years – 7 years, boys	82	27	0.50	0.50	0.36	0.50	0.20
8 years – 12 years, boys	90	19	0.50	0.50	0.50	0.61	0.28
13 years – 18 years, boys	82	30	0.50	0.50	0.52	0.75	0.51
1 year – 2 years, girls	29	31	0.40	0.50	0.33	0.48	0.21
3 years – 7 years, girls	87	29	0.40	0.50	0.37	0.52	0.26
8 years – 12 years, girls	91	27	0.40	0.50	0.38	0.53	0.21
13 years – 18 years, girls	80	36	0.40	0.50	0.41	0.64	0.35

GM of $DIc_{>0}$ and $DIc_{>0,\ per\ gender}$ for men and women was in the same range of values and milk consumption for these categories appeared to be strictly the same. But, for children older than 2, boys' milk consumption was higher than the girls' one, which could be the source of variations in GM of $DIc_{>0}$ and $DIc_{>0,\ per\ gender}$.

Results for GM of $DIc_{>0}$ and $DIc_{>0,\ per\ gender}$ for Minsk city were comparable to Narovlya district's ones. Only milk data for children were available (cf. Table 14) and they showed that boys' milk consumption decreased less quickly with age than the girls' one.

Table 14: Daily consumption of fresh milk for children from Minsk city, per age and gender categories ($L.d^{-1}$)

Category	# of people	% of non-consumers	Median ($L.d^{-1}$)		Average ($L.d^{-1}$)		Standard deviation ($L.d^{-1}$)
			for all	for consumers	for all	for consumers	for consumers
1 year – 2 years, boys	87	10	0.30	0.36	0.35	0.39	0.28
3 years – 7 years, boys	378	10	0.24	0.25	0.31	0.35	0.28
8 years – 12 years, boys	210	8	0.22	0.22	0.32	0.35	0.33
13 years – 18 years, boys	113	12	0.20	0.22	0.30	0.34	0.32
1 year – 2 years, girls	100	13	0.30	0.30	0.33	0.38	0.27
3 years – 7 years, girls	386	12	0.20	0.22	0.27	0.31	0.27
8 years – 12 years, girls	268	11	0.11	0.13	0.22	0.25	0.24
13 years – 18 years, girls	150	17	0.11	0.17	0.21	0.26	0.33

The milk consumption didn't seemed to be at the origin of variations observed in the results of GM of $DIc_{>0}$ calculations between male and female categories for Minsk city, on the contrary to Narovlya district.

4.3. Settlement effect

This study took into account different kind of settlements: a city (Minsk), a town (Narovlya) and villages. One of the different origins for variations due to settlement was already taken into account in $DIc_{>0}$ calculations: fallout deposition varies according to the location, the level and kind of ^{131}I deposition. Habits, and especially dietary habits were different from a rural to an urban area, as we saw with the milk consumption. But results of GM of $DIc_{>0}$ calculations for Narovlya district's villages presented important differences (cf. Table A5 in Annexes).

No clear explanation appeared to interpret these results. GM values were not correlated to ^{137}Cs or ^{131}I deposition (cf. Figures 17 and 18), neither to the number of children (cf. Figure 19).

Figure 17: GM of $DIc_{>0}$ per settlement for people from Narovlya district, according to the ^{137}Cs level ($kBq.m^{-2}$)

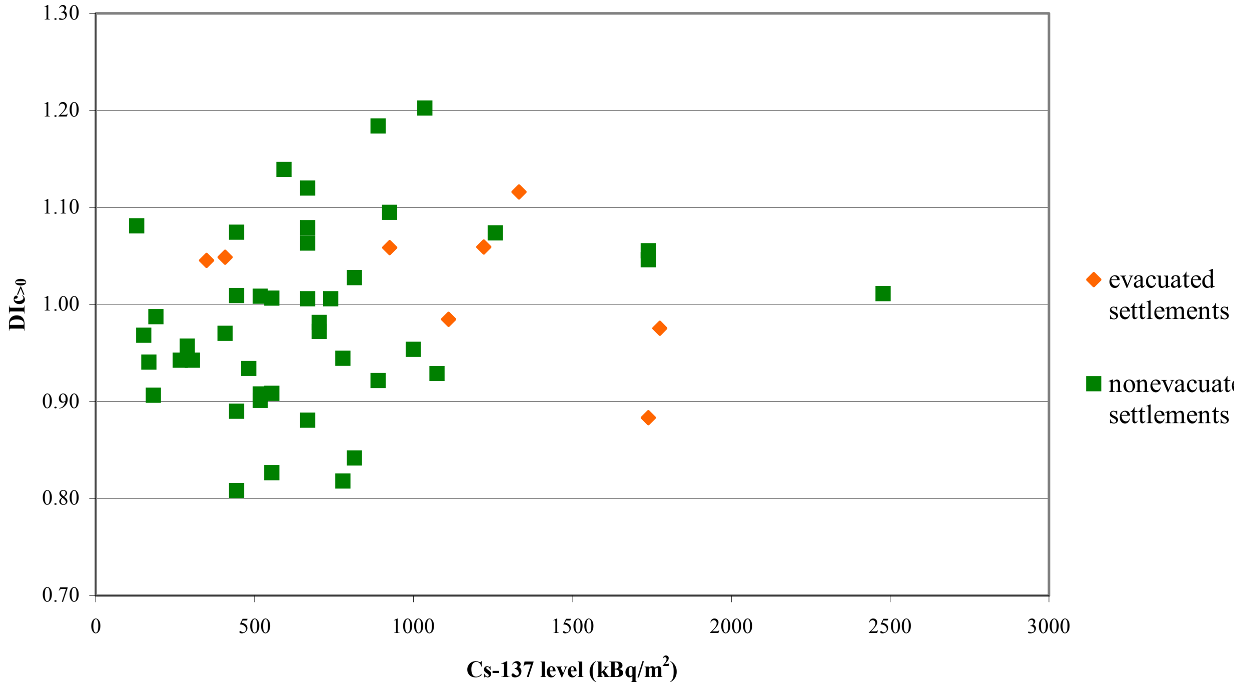


Figure 18: GM of $DIc_{>0}$ per settlement for people from Narovlya district, according to the ^{131}I level ($kBq.m^{-2}$)

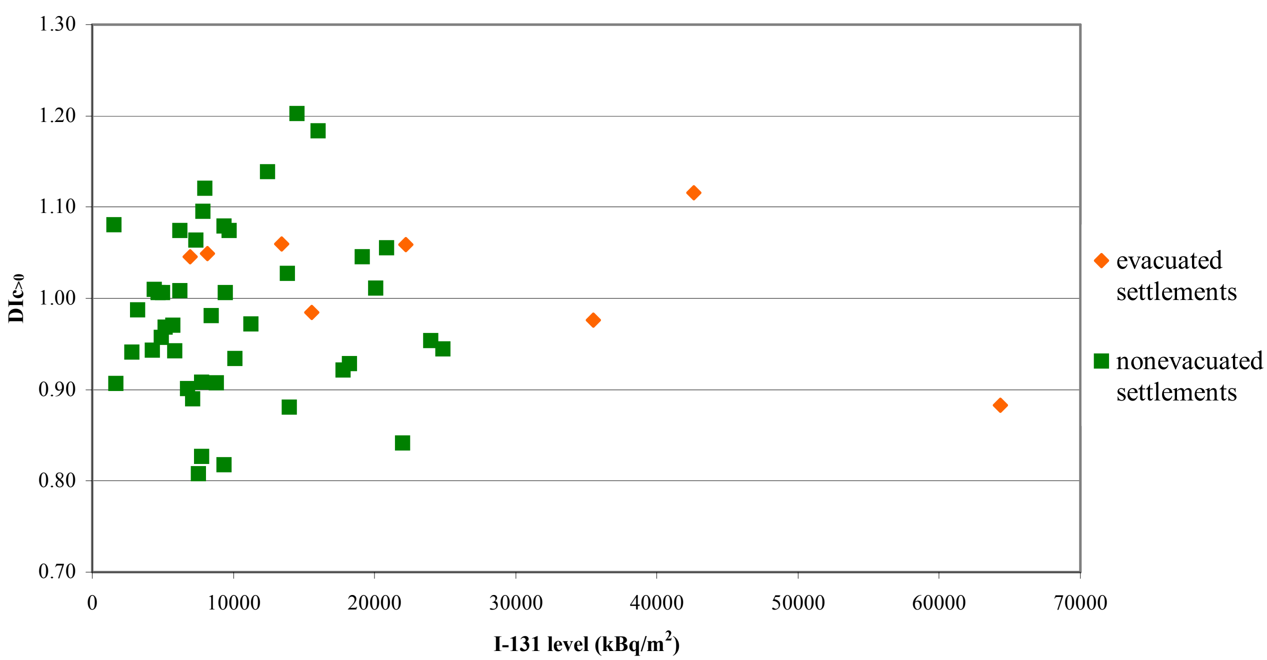
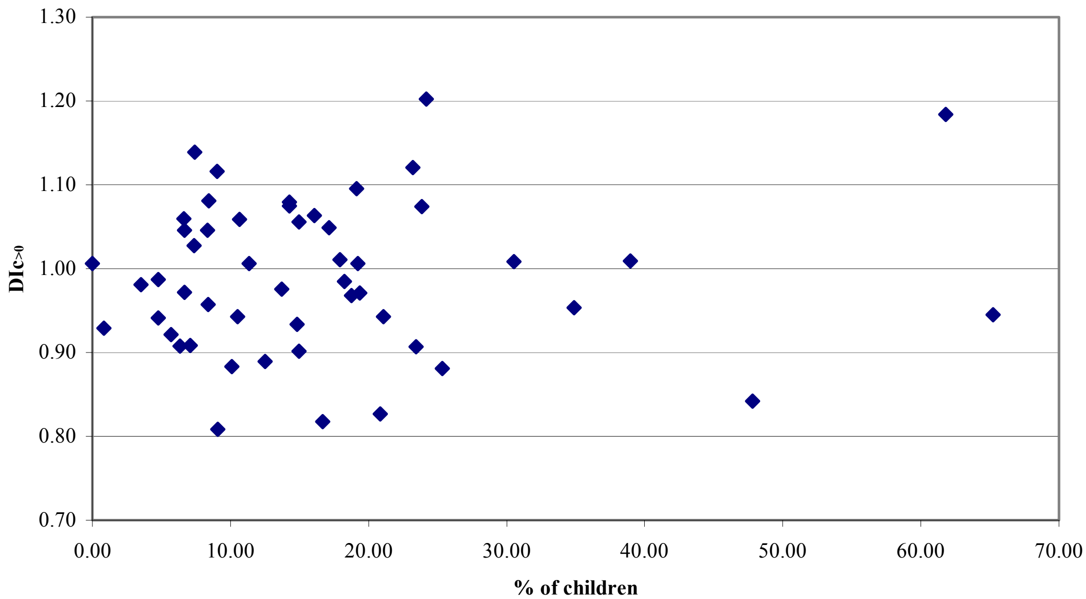


Figure 19: GM of $DIc_{>0}$ per settlement for people from Narovlya district, according to the proportion of children in the settlement



4.4. Date of measurement

Another factor that could effect on thyroid dose assessment is the date of measurement. We calculated GM and GSD of $DIc_{>0}$ for several range of dates, respectively for people from Narovlya district and Minsk city per age category (cf. Table A6 in Annexes and Figures 20 and 21). These data were also analyzed regarding to the field "rate": a lot of people presented a "rate" equal to zero, especially during the last days of May and during June 1986 for inhabitants from Minsk city.

Figure 20: GM of $DIc_{>0}$ for people from Narovlya district, per date of measurement and age category

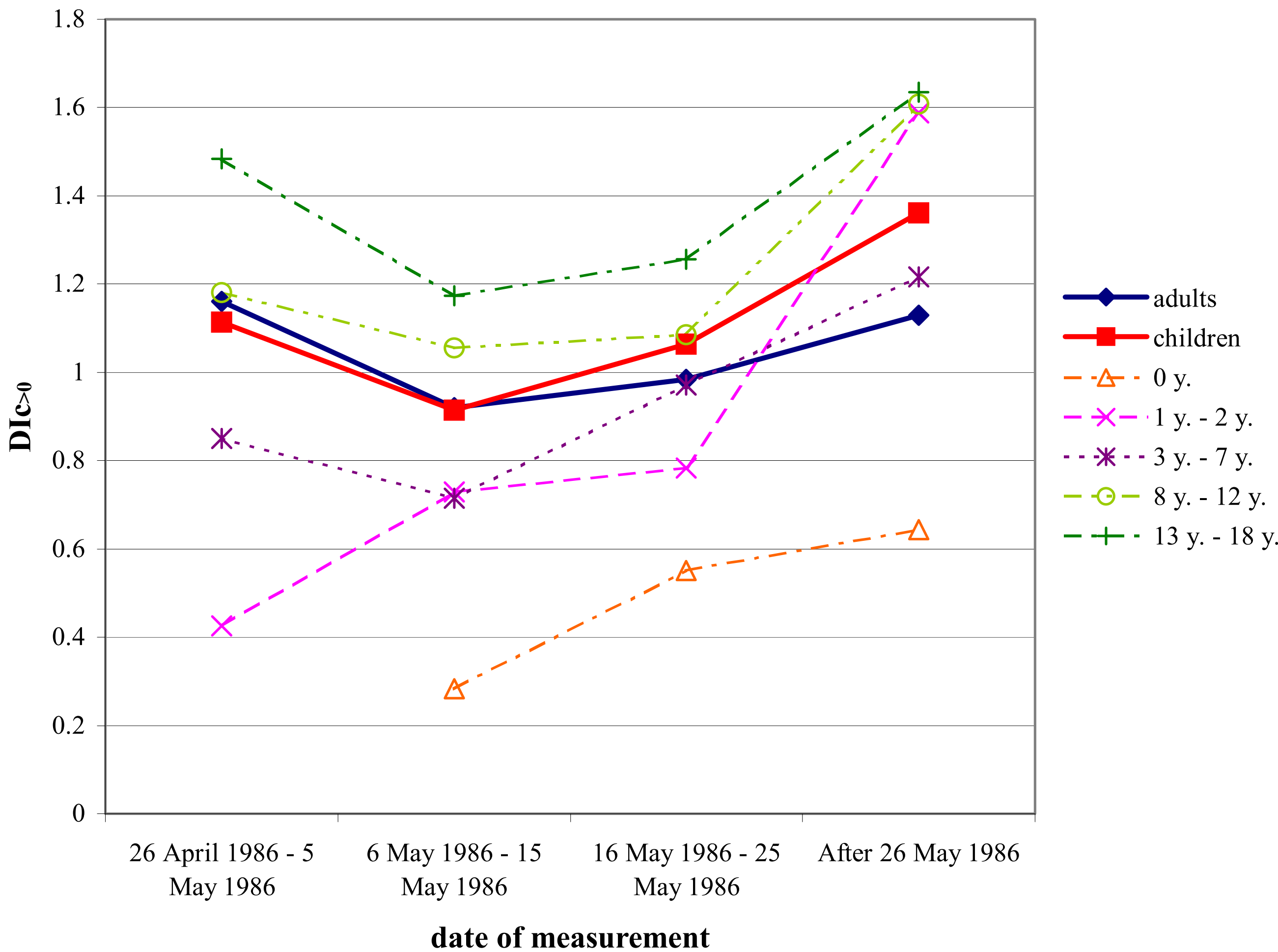
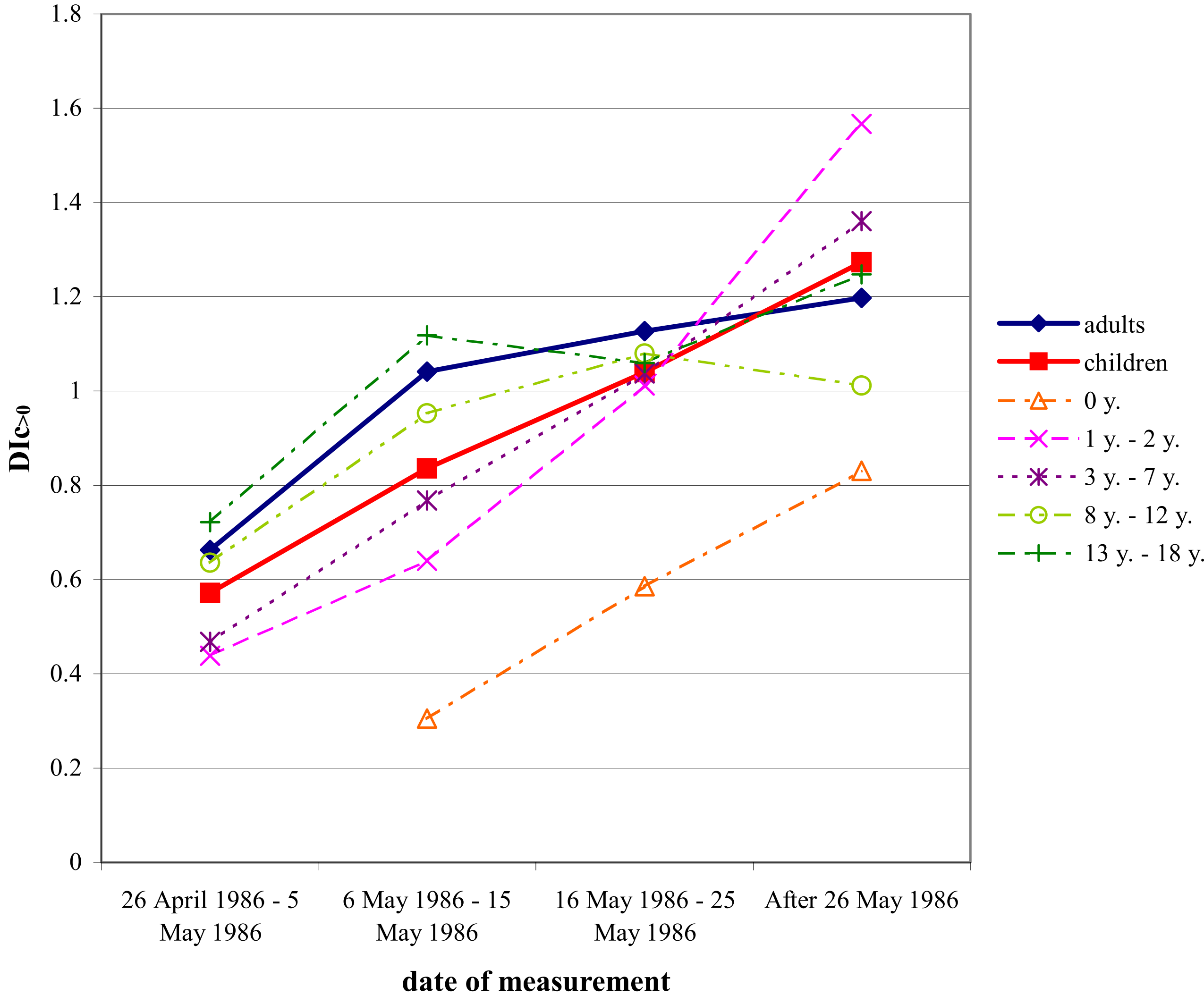


Figure 21: GM of $DIc_{>0}$ for people from Minsk city, per date of measurement and age category



The results per category of date of measurement were quite different. We could observe for Narovlya district two different tendencies: first a decrease of $DIc_{>0}$ till 6 May 1986 and then an increase, except for children aged 0 for whom we hadn't any value for the first period and for children aged 1 to 2 for whom the increase could be seen from the beginning of measurements. The $DIc_{>0}$ function according to the date of measurement for Minsk city presented a rise from the first measurements to the last ones, except for children aged 8 to 12 for whom a decrease could be observed after 25 May 1986.

This effect could be explained with the environmental conditions at the time of measurement, with characteristics of the devices used for measurement, and also how the records in the databases were done.

Regarding the environmental conditions at the time of measurement, we should notice that:

- In Narovlya district, the signal due to the background was very high at the beginning, because of the high contamination level, and so the signal of background appeared to be equal to the signal of thyroid activity for measured people. Then the environment was cleaner but people still very highly contaminated; a higher rate was recorded.
- In Minsk city, the environment was relatively clean of fallout deposition and people were less contaminated. Signal was more detectable at the beginning of the measurement campaign and then under the limit of detection, when less people were recorded.

Tendency showing higher doses for people with later measurements devices could be explained by the way of selection of the date of measurement recorded in the database and the maximum level of exposure rate readable on the devices used for measurement, at least for people who were measured several times in hospitals with SRP-68-01. 707 adults with multiple direct thyroid measurements carried out in Belarussian hospital and residents from 3 villages in Khoiniki district were considered for analysis. They were primarily measured with SRP-68-01 devices that maximum level of detection was 3000 $\mu R.h^{-1}$. So for people with high thyroid exposure only results of measures obtained during late dates of measurements, i.e. when the signal was lower than 3000 $\mu R.h^{-1}$, were used to assess individual doses and thus a late date was recorded in the database. On the contrary, when the thyroid exposure was low, the earliest measurement could be used and thus an earlier date of measurement was recorded in the database.

4.5. Study of the extremes

We studied characteristics of the individuals with the 20 highest and the 20 lowest values of $DIc_{>0}$ in Narovlya district and in Minsk city (cf. Table A7 in Annexes).

For Narovlya district, the 20 lowest $DIc_{>0}$ were between 0.01 and 0.04. They have been calculated for people from evacuated villages (2), nonevacuated villages (12), and Narovlya town (6), aged 0 to 71, but essentially for adults (15). These people were evacuated on 2 May 1986 or later or not evacuated at all, and were subjected to measurement primarily between 6 May 1986 and 15 May 1986 (17). On the contrary, the 20 highest values of $DIc_{>0}$ were between 23.4 and 74.5, i.e. there was a factor about 7500 between the lowest and the highest values of $DIc_{>0}$. They have been calculated for people equally distributed between nonevacuated villages (10), and Narovlya town (10), aged 3 to 65, but essentially for children (11). The first date of evacuation for those people was 7 May 1986, and the range of their dates of measurement covered all the period from 26 April 1986 to June 1986.

For Minsk city, the 20 lowest $DIc_{>0}$ were between 0.04 and 0.06. They have been calculated for people aged 0 to 55, but essentially for children (14). These people were subjected to measurement primarily between 6 May 1986 and 15 May 1986 (15). On the contrary, the 20 highest values of $DIc_{>0}$ were between 11.67 and 14.84, i.e. there was a factor about 370 between the lowest and the highest values of $DIc_{>0}$. They have been calculated for people aged 5 to 42, but essentially for adults (16). The range of their dates of measurement covered all the period from 6 May 1986 to June 1986 (13 people after 26 May 1986).

Very high factors were observed between highest and lowest values of $DIc_{>0}$: 7500 for Narovlya district (and about 500 for children from Narovlya district aged 1 to 2, about 100 for children from evacuated villages aged 0 to 2), and 370 for Minsk city (and about 50 for children aged 0, about 230 for children aged 1 to 2). Different assumptions could be proposed to explain such variability, linked to the direct thyroid measurements, to the model used to assess thyroid doses, to personal characteristics, or to their combination.

The high variability observed between highest and lowest values of $DIc_{>0}$ could be linked to the direct thyroid measurements:

- The environmental conditions during measurements could have led to misinterpretation of the measure: a very "dirty" environment polluted the background activity level, and some people wore contaminated clothes.
- Devices used for direct thyroid measurement were very simple, with output in exposure or count rates, and not specially designed for a monitoring of human thyroid.
- Because of the emergency after the Chernobyl accident, devices for measurement were used in different conditions, in clinics, hospitals, sanatoria, rest houses, summer camps for children, even by mobile teams. These direct thyroid measurements could have been done by inexperienced personal that was not familiar to this kind of devices and measurements. Likelihood of mistakes in calibration, during the measure of thyroid gland and background activities, or of result misreading was high. Furthermore confidence intervals and limit of detection were not very good in field conditions.

Also this high variability could be linked to the model used to assess thyroid doses for people with direct thyroid measurement:

- The model could have overestimated the thyroid doses for some people, because it didn't consider food intakes other than fresh milk or continuous food intakes: natural biological elimination could have been less important than presumed.
- The model introduced correction factors to take into account bias due to the devices and their uses. We decided to re-correct the values obtained, because this bias still occurred. These successive global corrections could have led to very high variation of the results for some individuals.

Eventually, this high variability could be linked to personal characteristics, recorded or not in the databases:

- The balance of adults' number regarding to the children's one in the 20 lowest and highest values of $DIc_{>0}$ was different in Minsk city's case and Narovlya district's case. Age seemed to have different effect in urban and rural area for these extreme values, perhaps because of different food consumption. Also the effect of age could be due to a discrepancy between "real" thyroid volumes and the ones used in this study, issued by the ICRP. Another parameter linked to the age is the thyroid uptake fraction, which was considered uniform for each class of age.

- The lack of personal data about food consumptions (fresh milk, leafy vegetables...), about the conditions of exposure (very few samples of soil, grass and milk were measured; kind of deposition in the settlement was not always recorded), and about the direct thyroid measurement conditions made very hard to really take into account personal characteristics.
- The way dates of measurement were recorded in the database, and sometimes "restored" (by people who computerized the handwritten notebooks) could have led to misinterpretation of the results. The date of measurement seemed to have the same effect in Narovlya district's case and Minsk city's case, but smoother for the first one.

Uncertainty appeared to be very large from an individual to another, without any clear explanation from personal data. Then we preferred not to consider thyroid doses individually.

5. Conclusion

The suggested corrected dose index $DIc_{>0}$ can be helpful to analyze thyroid doses for wide range of settlements, ages and behaviors. This study showed that the values for individual thyroid doses presented in Narovlya district database and in Minsk city database were quite consistent when considered per age group, gender or settlement, but not very reliable when considered individually. The very high GSD showed a large uncertainty.

No bias according to the age was really observed, except for very young children, especially from evacuated villages in Narovlya district. However biases were detected linked to the corrected exposure rate ("rate") of the activity in thyroid glands, to the IDIndex device used for the direct thyroid measurement and to the date of this measurement.

Numerous corrected exposure rates recorded in Narovlya district and Minsk city databases were equal to zero. The origin of these values was not very clear, probably linked to the background level at the time of measurement, to assessment method of the corrected rate, to the low precision of measurement devices, or to the primitive conditions in which some measurements were done.

Another bias, linked to the IDIndex device, occurred, certainly due to different causes, as: how the devices were manipulated, how they were calibrated according to the size of the patient, their limit of detection, how backgrounds were assessed, etc. The lack of information on these questions didn't permit to correct the bias due to conditions of measurement for each individual thyroid dose but some general correction factors were introduced.

And a bias due date of measurement was detected, especially for children. This bias could be linked to the method of recording for the dates of measurement.

The general information given by Narovlya district and Minsk city databases were very consistent when we considered people by categories, as the values of geometric means for the dose indexes $DIc_{>0}$ were very often close to 1. The different variations observed could have found their origins in fresh milk consumption habit or in environmental conditions of measurement or in record patterns. More pieces of information about food consumption, as reliable data on milk consumption or vegetable consumption, and for more people would be useful to study the variability. We didn't consider the iodine prophylaxis in this study because too few people were concerned or answered this question during the 1988 round of interview. The lack of personal data combined with the high variability of the results, as shown with geometric standard deviation of doses indexes higher than 3 or 4 led us not to consider individually the extremes values of preliminary thyroid doses estimates.

However databases are now revised at the Institute of Biophysics, Moscow: computerized data are systematically compared to originals notebooks and a new field with the value of the background measurement is added. In two years, these new databases, with better doses estimates, will be available, and this kind of analysis using dose index will be helpful to determine the quality and reliability of the new thyroid dose estimates.

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7. Annexes

Table A1: Fields of the databases, combining interviews from 1988, direct thyroid measurement from May-June 1986 and initial dose assessments [Shinkarev, 1999]

Fields	Meaning
IND_CODE	Individual code (describing the region, district and settlement)
REGION	District
POPUL_AREA	Settlement
PROF	Profession
BIRTH	Year of birth 1,000 if unknown
VYPAS	Date when cows began to consume pasture grass
COM_VYPAS	if there is an "*" in this field, it means that no answer was available for the field VYPAS, and so the assigned date in VYPAS is the most probable date for the settlement if there is nothing in that field: the date given by the person is recorded in VYPAS
DATE_GONE	Date when the person left the settlement
COM_GONE	if there is an "*" in this field, it means that no answer was available for the field DATE_GONE, and so the assigned date in DATE_GONE is the most probable date for the settlement if there is nothing in that field: the date given by the person is recorded in DATE_GONE
MOLOKO	Daily rate of consumption of fresh milk between April 26, 1986 and May 31, 1986 -1: no answer available 0: no milk consumption
BLOKADA	Date when the person started taking KI pills
KOL_BLOK	Number of days when the person took KI pills -1: number of days unknown
STOP_MILK	Date when the person stopped consuming fresh milk
MEAS_DATE	Date when the person was measured (measurement selected to determine ^{131}I thyroidal content) No date: no measurement available
MEAS_RATE	Exposure rate against the thyroid (background deducted)
INDEX ("IDIndex")	Reference record: place of measurement and instrument (5: DP-5, 8: SRP 68-01)
SIGN	>: actual exposure rate against thyroid was greater than written in MEAS_RATE <: actual exposure rate against thyroid was lower than written in MEAS_RATE nothing: actual indications of the instrument were recorded

Table A1 (continued): Fields of the databases, combining interviews from 1988, direct thyroid measurement from May-June 1986 and initial dose assessments [Shinkarev, 1999]

Fields	**Meaning**
RATE	Product of the field MEAS_RATE and a correction factor
DOSE	If RATE ≠ 0: the individual thyroid dose estimate is recorded If RATE = 0: 5. the average dose was calculated for the adults with nonzero thyroid dose in a settlement 6. in rural settlement, the ratio of ingestion intake of ^{131}I to inhalation of ^{131}I = 20 (for people who stayed all the time and consumed fresh milk locally produced without stop), correction factors 7. 1/20th of the "new" dose = inhalation dose for adult 8. inhalation dose for children: basis = inhalation dose for adult, and correction factors 9. inhalation doses were assigned to those people for whom the background was greater than or equal to the signal

Table A2: Thyroid mass values (*tm*)

Age *j* (y)	**Thyroid mass (g) [IRCP 56]**	**Interpolation***	***tm(j)* (g)**
0	1.29	-	1.5
1	1.78	-	2.0
2	-	$tm(a) = 0.4175 \times a + 1.3625$	2.4
3	-		2.8
4	-		3.2
5	3.45	-	3.9
6	-	$tm(a) = 0.896 \times a - 1.03$	4.8
7	-		5.7
8	-		6.6
9	-		7.5
10	7.93	-	8.4
11	-	$tm(a) = 0.894 \times a - 1.01$	9.3
12	-		10
13	-		11
14	-		12
15	12.4	-	13
16	-	$tm(a) = 1.52 \times a - 10.4$	15
17	-		16
18	-		18
adult	20	**	20

*: middle of the age was considered for *a*, e.g. *j* = 10 means 10 years and 6 months.
**: value for adults is assumed to correspond to age 20.

Table A3: GM of *DI*, of $DI_{>0}$ and of $DI_{>0, per\ gender}$, per device

IDIndex	DI			$DI_{>0}$			$DI_{>0, males}$			$DI_{>0, females}$		
	N	GM	GSD	N	GM	GSD	N	GM	GSD	N	GM	GSD
Narovlya district												
B5	18	1.39	5.03	17	1.56	3.31				12	1.52	3.57
B8	38	2.20	2.82	38	2.06	2.84	16	2.63	1.80	20	1.97	3.13
BGOB	26	2.77	1.97	26	2.51	2.08	13	2.30	2.09	13	2.77	2.06
BM	134	1.47	2.70	134	1.39	2.68	53	1.21	3.01	73	1.34	2.27
BM8	68	1.75	2.21	68	1.31	2.21	23	1.26	2.19	10	1.87	1.83
BMR5	15	1.43	2.69	15	1.07	2.69						
BNR	25	1.86	3.65	24	2.01	3.40				12	1.60	4.02
BPOT5	25	0.95	3.96	24	0.99	3.74				14	1.07	3.67
V5	641	0.94	3.12	564	1.00	2.26	253	1.05	2.26	295	0.98	2.27
GVR	26	1.07	3.05	26	1.03	3.07				13	0.84	2.91
GZhR5	17	0.80	2.53	17	0.60	2.53				11	0.72	2.74
GMR	242	0.47	4.21	209	0.59	3.63	57	0.58	3.65	77	0.67	3.50
GMR5	284	0.69	4.60	231	0.81	3.76	52	0.90	3.36	62	0.83	3.34
GPR	56	0.50	2.71	56	0.46	2.81	24	0.50	2.25	22	0.39	2.89
GPR5	51	0.63	3.14	50	0.49	3.11	14	0.42	3.13	34	0.55	3.17
GRAR	96	1.43	2.77	96	1.43	2.77	40	1.65	3.01	49	1.30	2.60
GRR	17	3.22	1.79	17	3.18	1.79				12	2.61	1.67
D	29	1.28	2.62	29	1.28	2.62	10	1.11	2.96	15	1.03	2.22
IBF	77	1.38	2.19	77	1.03	2.19	15	1.07	1.95	46	1.12	2.31
KR5	22	2.41	3.70	22	1.80	3.70	11	0.99	3.23			
M035	33	0.33	4.10	30	0.32	3.98	10	0.20	3.97			
MOZ5	18	0.32	3.73	13	0.44	3.36						
MOZ8	15	0.85	2.25	15	0.85	2.25						
NR	589	1.11	3.04	589	1.05	3.04	231	1.06	2.89	231	1.00	3.25
NR5	1356	1.15	3.04	1245	1.04	2.59	483	1.04	2.51	346	1.08	2.57
NR8	852	0.89	3.38	703	1.01	2.46	127	0.95	2.42	140	1.01	2.23
O	256	0.98	2.50	253	0.98	2.42	112	0.96	2.77	138	0.92	2.13
O5	43	1.14	2.57	40	1.00	2.15	13	1.16	2.16	22	1.17	2.15
P	266	1.11	3.11	265	1.03	3.04	115	1.13	3.16	142	0.97	3.05
P28M8	529	0.98	3.78	493	0.87	3.32	93	0.88	3.54	109	0.70	3.05
P5	376	0.88	4.30	276	1.32	2.84	92	1.20	3.01	84	1.41	2.69
PET5	18	0.34	2.24	17	0.32	1.92	10	0.29	2.24			

Table A3 (continued): GM of *DI*, of $DI_{>0}$ and of $DI_{>0, per gender}$, per device

IDIndex	DI			$DI_{>0}$			$DI_{>0, males}$			$DI_{>0, females}$		
	N	GM	GSD	N	GM	GSD	N	GM	GSD	N	GM	GSD
Narovlya district												
POT5	24	1.03	2.84	24	0.77	2.84				15	0.88	3.00
PR5	50	1.18	2.97	49	0.95	2.65	13	1.32	2.31	32	0.97	2.82
REChR	55	0.76	1.96	54	0.72	1.89	17	0.62	1.66	25	0.83	1.77
RR	70	1.49	3.36	70	1.48	3.35	28	1.38	4.28	40	1.53	2.82
S8	534	0.70	4.61	408	0.94	3.37	87	0.72	3.22	88	1.26	3.30
F	1596	1.06	2.64	1584	1.01	2.60	691	0.96	2.67	800	1.01	2.52
F5	18	0.75	2.72	17	0.62	2.54	14	0.65	2.72			
F8	12	0.60	3.61									
ENO5	304	1.18	3.26	275	1.30	2.46	136	1.38	2.36	138	1.16	2.50
ENSsh5	66	1.04	2.81	63	1.06	2.36	30	1.34	2.43	33	0.83	2.05
EKOR5	85	0.83	4.43	84	0.79	4.38	29	1.07	4.98	54	0.61	3.89
EMOZ5	97	1.12	3.92	97	1.11	3.91	42	1.27	3.83	52	1.09	4.07
ENAR5	107	1.23	2.84	99	1.12	2.31	53	1.25	2.04	29	1.14	1.88
EP5	632	1.29	3.46	589	1.26	2.45	206	1.47	2.66	322	1.25	2.30
EP8	98	1.14	3.03	96	1.17	2.88	38	1.14	3.04	57	1.13	2.79
EF5	426	1.17	2.76	423	1.11	2.68	151	1.15	2.86	223	1.04	2.42
no device	2038	0.97	3.26	1398	0.98	2.96	588	1.00	2.75	746	0.99	3.00
Minsk city												
M28P8	13135	0.94	4.52	10043	1.10	2.52	2106	1.07	2.50	2806	1.17	2.46
M5P8	4684	1.26	1.97	4649	0.75	1.90	1085	0.74	1.98	1924	0.80	1.90

Table A4: $GM(d_{meas}(ad, S))$ per settlement S, ^{137}Cs and ^{131}I deposition and other thyroid dose assessments

	Current study				[Gavrilin, 2002]			[Germenchuk, 2002]			[Drozdovich et al., 1989]	
settlement	evacuated (e) or not (n)	# of people w/ DTM and DOB	# adults	$GM(d_{meas}(ad, S))$	Cs-137 (Ci/km^2)	I-131 / Cs-137	# adults	Evacuated (E) or Nonevacuated (N) zone	Inhabitants (I) or No Inhabitants (NI) in the village	Cs-137 (Ci/km^2)	population	Cs-137 (Ci/km^2)
Minsk city	n	17,819	11,484	0.8								
Narovlya	n	5,307	3,673	12	14	12	3717	N	I	19	11165	17
Alexandrovka	n	7	4	nc				N	I	3.1	156	4
Antonov	n	120	73	17	12	9.9	74	N	I	15	337	15
Antonovka	n	13	6	nc				E	NI	15-40		
Beleya Bereza	n	3	3	nc				-	-	-		
Beleya Soroka	e	137	125	14	36	32	126	E	NI	>40		
Beloberezh. Rudnya	n	252	210	6	18	11	212	E	NI	5-15		
Belyi Bereg	n	89	79	13	20	6.3	79	N	NI	23.1		
Berezovka	n	3	1	nc				E	NI	15-40	118	26
Borovichi	n	94	86	16	7.2	22	86	E	NI	5-15		
Bratskoe	n	86	79	20	3.5	12	81	N	I	2.8	92	5
Buda	n	11	10	25	12	17	10	N	I	10.9	411	11
Buda Krasnovskaya	n	66	63	21.40	5.1	17	63	N	I	5	148	5
Budki	n	240	204	29	13	21	207	N	I	11.5	390	11
Buk	n	70	63	9	22	17	63	N	NI	24.7		
Vepry	e	121	113	28	33	11	114	E	NI	>40		
Verbovichi	n	378	242	27	27	24	243	N	I	19.1	744	18
Vyazhishcha	n	24	19	29	15	14	19	E	NI	5.4		
Gabrileevka	n	32	26	20	4.1	34	26	N	I	3.2	82	4
Gazhin	n	433	345	28	8.2	14	348	N	I	8.4	454	9
Gamarnya	n	17	14	13	12	16	14	-	-	-		

DTM: Direct Thyroid Measurement, DOB: Date Of Birth, na: not available, nc: not calculated

Table A4 (continued): $GM(d_{meas}(ad, S))$ per settlement S, ^{137}Cs and ^{131}I deposition and other thyroid dose assessments

	Current study				[Gavrilin, 2002]			[Germenchuk, 2002]			[Drozdovich et al., 1989]	
settlement	**evacuated (e) or not (n)**	**# of people w/ DTM and DOB**	**# adults**	$GM(d_{meas}(ad, S))$	**Cs-137 (Ci/km^2)**	**I-131 / Cs-137**	**# adults**	**Evacuated (E) or Nonevacuated (N) zone**	**Inhabitants (I) or No Inhabitants (NI) in the village**	**Cs-137 (Ci/km^2)**	**population**	**Cs-137 (Ci/km^2)**
Golovchitskaya Buda	n	140	104	22	18	21	104	-	-	-		
Golovchitsy	n	573	535	10	19	16	568	N	I	15.5	865	16
Gridni	n	69	36	34	22	27	36	E	NI	15-40		
Grushevka	n	143	50	11	21	32	52	N	I	16		
Guta	n	3	1	nc				N	I	17.6	63	17
Danileevka	n	2	2	nc				E	NI	15-40		
Dvorishche	n	80	74	39	14	17	74	-	-	-		18
Demidov	n	276	237	20	14	13	237	N	I	12.2	362	13
Dernovichi	n	272	205	14	28	14	206	E	NI	15-40		
Dzerzhinsk	n	36	30	19	21	12	30	N	I	16		
Dovlyady	e	334	273	31	30	14	285	E	NI	>40		
Dubrava	n	165	142	16	47	12	144	E	NI	>40		
Dyatlick	n	1	1	nc				N	I	3.6	35	4
Zavoit	n	199	192	13	19	12	192	N	I	15.1	554	16
Karpovichi	n	110	84	16	34	7.7	109	E	NI	>40		
Kirov	n	220	84	14	24	18	86	N	I	27.8	1077	31
Konotop	n	213	201	21	24	20	208	N	I	23.7	484	25
Krasnoska	n	167	159	22	4.5	17	160	N	I	5	287	5
Laska	n	4	2	nc				-	-	-	188	13
Lelev	n	0		na								
Lenposelok	n	109	76	29	18	12	76	E	NI	5-15		
Linov	n	131	120	28	7.8	17	126	N	I	6.8	189	7
Lisava	n	15	15	11	18	7.5	15	E	NI	>40		

DTM: Direct Thyroid Measurement, DOB: Date Of Birth, na: not available, nc: not calculated

Table A4 (continued): $GM(d_{meas}(ad, S))$ per settlement S, ^{137}Cs and ^{131}I deposition and other thyroid dose assessments

	Current study				[Gavrilin, 2002]			[Germenchuk, 2002]			[Drozdovich et al., 1989]	
settlement	evacuated (e) or not (n)	# of people w/ DTM and DOB	# adults	$GM(d_{meas}(ad, S))$	Cs-137 (Ci/km^2)	I-131 / Cs-137	# adults	Evacuated (E) or Nonevacuated (N) zone	Inhabitants (I) or No Inhabitants (NI) in the village	Cs-137 (Ci/km^2)	population	Cs-137 (Ci/km^2)
Likhovnya	n	0		na								
Luben	n	133	132	36	29	17	132	N	I	26.9	207	27
Maidan	n	4	2	nc				E	NI	15-40		
Maltsy	n	0		na								
Mikhailovka	n	86	80	9	16	21	80	E	NI	15-40		
Moskalevka	n	160	148	20	15	14	153	N	I	17	129	17
Nadtochaevka	e	101	91	16	47	37	92	E	NI	>40		
Nichporovka	n	10	7	nc				N	I	16.2	90	22
Okopy	n	72	55	19	4.9	9.2	55	E	NI	5-15		
Osipovka	e	49	44	30	25	24	44	E	NI	>40		
Pobeda	n	0		na								
Radomlya	n	25	23	33	47	11	23	E	NI	>40		
Reka Slovechno	n	2	2	nc				-	-	-		
Rozhava	e	53	45	60	48	20	46	E	NI	>40		
Romanovka	n	10	9	nc				N	I	20.7	175	22
Rudnya	n	1	0	nc				-	-	-		
Rudnya Barsuck	n	1	0	nc				-	-	-		
Svecha	n	78	63	16	15	17	64	N	I	10.9	97	11
Sergeev Cvhutor	n	8	8	nc				N	I	3.9	15	6
Smolegov	n	6	3	nc				N	I	24.6	357	23
Smolegovskaya Rudnya	n	3	2	nc				N	I	31.8	202	35
Teshkov	n	95	75	15	11	14	157	E	NI	5-15		
Tikhin	n	108	88	6	25	8.5	88	E	NI	15-40		

DTM: Direct Thyroid Measurement, DOB: Date Of Birth, na: not available, nc: not calculated

Table A4 (continued): $GM(d_{meas}(ad, S))$ per settlement S, ^{137}Cs and ^{131}I deposition and other thyroid dose assessments

	Current study				[Gavrilin, 2002]			[Germenchuk, 2002]			[Drozdovich et al., 1989]	
settlement	evacuated (e) or not (n)	# of people w/ DTM and DOB	# adults	$GM(d_{meas}(ad, S))$	Cs-137 (Ci/km^2)	I-131 / Cs-137	# adults	Evacuated (E) or Nonevacuated (N) zone	Inhabitants (I) or No Inhabitants (NI) in the village	Cs-137 (Ci/km^2)	population	Cs-137 (Ci/km^2)
Ugly	n	546	450	22	67	8.1	457	E	NI	>40		
Physinki	n	3	3	nc				N	I	11.3	150	11
Khatki	e	113	94	23	11	20	94	E	NI	5-15		
Khilchikha	n	92	79	27	18	14	102	N	I	22.1	165	23
Khomenki	n	16	3	nc				N	I	16.8	114	25
Khutor Les	e	60	56	29	9.4	20	56	E	NI	5-15		
Chapaevka	n	9	5	nc				E	NI	5-15		
Chekhi	n	0		na								
Yasenok	n	96	81	11	12	14	81	E	NI	5-40		
Krasnyi Borets	n	0		na								
Narovlya district		12,705	9,709									

DTM: Direct Thyroid Measurement, DOB: Date Of Birth, na: not available, nc: not calculated

Table A5: GM and GSD of $DIc_{>0}$ for people from Narovlya district, per settlement

Category	# of people	GM	GSD
Narovlya town	4,546	1.01	2.79
Antonov	118	1.01	2.92
Beleya Soroka	133	1.12	2.03
Beloberezh. Rudnya	249	1.06	4.48
Belyi Bereg	88	1.01	3.37
Borovichi	76	0.94	3.38
Bratskoe	83	1.08	3.05
Buda	11	0.81	3.49
Buda Krasnovskaya	63	0.99	2.20
Budki	236	0.93	2.94
Buk	68	1.03	2.33
Vepry	121	1.06	2.64
Verbovichi	370	0.95	2.89
Vyazhishya	24	0.83	4.04
Gabrileevka	32	0.97	2.08
Gazhin	403	0.94	2.57
Gamarnya	16	0.89	3.29
Golovchitskaya Buda	138	0.88	2.78
Golovchitsy	556	0.97	2.69
Gridni	69	0.84	3.09
Grushevka	138	0.94	2.97
Dvorishche	79	0.91	2.65
Demidov	254	0.90	2.45
Dernovichi	269	1.20	3.37
Dzerzhinsk	36	0.82	2.84
Dovlryady	329	0.98	3.04
Dubrava	147	1.06	2.10
Zavoit	199	0.98	2.39
Karpovichi	109	1.07	2.74
Kirov	212	1.18	3.35
Konotop	211	0.92	3.14
Krasnovka	167	0.94	2.20
Lenposelok	99	1.12	2.47
Linov	131	0.96	2.11
Lisava	10	1.01	1.63
Luben	119	0.93	2.59
Michailovka	81	1.14	2.64
Moskalevka	155	0.91	2.87

Table A5 (continued): GM and GSD of $DIc_{>0}$ for people from Narovlya district, per settlement

Category	# of people	GM	GSD
Nadtochaevka	99	0.88	3.09
Okopy	64	0.91	2.80
Osipovka	47	1.06	2.42
Radomlya	24	1.05	2.01
Rozhava	51	0.98	3.54
Svecha	78	1.01	2.31
Teshkov	93	0.97	2.46
Tikhin	94	1.10	1.93
Ugly	507	1.01	2.58
Khatki	105	1.05	2.83
Khilchikha	91	1.08	2.74
Khutor Les	60	1.05	2.92
Yasenok	91	1.07	2.17

Table A6: GM and GSD of $DIc_{>0}$ for people from Narovlya district Minsk city, per date of measurement and age category

Date of measurement:		26 April 1986 - 5 May 1986	6 May 1986 - 15 May 1986	16 May 1986 - 25 May 1986	After 26 May 1986
Narovlya district					
adults	#	312	2583	4769	1239
	GM	**1.16**	**0.92**	**0.98**	**1.13**
	GSD	2.56	3.10	2.57	2.60
children	#	48	1174	1019	405
	GM	**1.11**	**0.91**	**1.06**	**1.36**
	GSD	2.92	3.11	2.90	2.56
0 y	#	1	28	10	11
	GM		**0.28**	**0.55**	**0.64**
	GSD		2.56	5.04	2.02
1 y –2 y	#	3	143	80	75
	GM	**0.43**	**0.73**	**0.78**	**1.59**
	GSD	3.22	3.24	2.86	2.80
3 y – 7 y	#	13	316	313	204
	GM	**0.85**	**0.71**	**0.97**	**1.22**
	GSD	4.13	2.98	2.89	2.46
8 y – 12 y	#	12	273	295	77
	GM	**1.18**	**1.06**	**1.08**	**1.61**
	GSD	2.30	2.93	2.86	2.54
13 y – 18 y	#	19	414	321	38
	GM	**1.48**	**1.17**	**1.26**	**1.63**
	GSD	2.42	3.02	2.82	2.46
Minsk city					
adults	#	910	4532	2165	1528
	GM	**0.66**	**1.04**	**1.13**	**1.20**
	GSD	1.89	2.10	2.46	2.48
children	#	302	2592	1851	812
	GM	**0.57**	**0.84**	**1.04**	**1.27**
	GSD	1.87	2.30	2.48	2.53
0 y	#	1	24	20	9
	GM		**0.30**	**0.59**	**0.83**
	GSD		2.09	2.55	2.99
1 y –2 y	#	32	390	312	137
	GM	**0.44**	**0.64**	**1.01**	**1.57**
	GSD	2.29	2.46	2.76	2.46
3 y – 7 y	#	90	1063	846	366
	GM	**0.47**	**0.77**	**1.04**	**1.36**
	GSD	1.90	2.33	2.51	2.55

Table A6 (continued): GM and GSD of $DIc_{>0}$ for people from Narovlya district Minsk city, per date of measurement and age category

Date of measurement:		26 April 1986 - 5 May 1986	6 May 1986 - 15 May 1986	16 May 1986 - 25 May 1986	After 26 May 1986
Minsk city					
8 y – 12 y	#	100	668	468	204
	GM	**0.64**	**0.95**	**1.08**	**1.01**
	GSD	1.62	2.11	2.29	2.40
13 y – 18 y	#	79	447	205	96
	GM	**0.72**	**1.12**	**1.06**	**1.25**
	GSD	1.67	2.06	2.28	2.54

Table A7: Characteristics of the individuals with the 20 highest and the 20 lowest values of $DIc_{>0}$ in Narovlya district and in Minsk city

Variable	Narovlya district		Minsk city	
	20 lowest values	20 highest values	20 lowest values	20 highest values
Settlement[3]	2 from EV 12 from NV 6 from NT	0 from EV 10 from NV 10 from NT	-	-
^{137}Cs deposition ($kBq.m^{-2}$)	300 to > 1,480	100 to > 1,480	2 to 4	2 to 4
Age	0 to 71 y. old	3 to 65 y. old	0 to 55 y. old	5 to 42 y. old
Adults	15	9	6	16
Children	5	11	14	4
Gender				
Males	4	10	6	8
Females	7	3	4	3
Unknown	9	7	10	9
Milk			(BelAm data)	(BelAm data)
Unknown	16	15	16	18
0 $L.d^{-1}$	3	1	0	0
> 0 $L.d^{-1}$ - ≤ 0.5 $L.d^{-1}$	0	3	4	1
> 0.5 $L.d^{-1}$ - ≤ 1 $L.d^{-1}$	1	1	0	1
> 1 $L.d^{-1}$ - ≤ 1.5 $L.d^{-1}$	0	0	0	0
> 1.5 $L.d^{-1}$ - ≤ 2 $L.d^{-1}$	0	0	0	0
KI pills				
Unknown	11	12	20	20
0	8	4	0	0
> 0	1	4	0	0
Dates of evacuation	2 May 1986 to 31 May 1986	7 May 1986 to 31 May 1986	Not evacuated	Not evacuated
IDIndex				
Known	15	17	20	20
(# of IDIndex)	(7)	(10)	(2)	(1)
Unknown	5	3	0	0
Date of measurement				
26 April - 5 May 1986	1	1	4	0
6 May - 15 May 1986	17	9	15	6
16 May - 25 May 1986	2	6	1	1
After 26 May 1986	0	4	0	13
Rate ($mR.h^{-1}$)	0.003 to 0.030	1.200 to 20.680	0.001 to 0.004	0.060 to 0.200
Dose (cGy)	0.24 to 3.40	275 to 3,959	0.06 to 1.14	12.34 to 100
$DIc_{>0}$	0.01 to 0.04	23.4 to 74.5	0.04 to 0.06	11.67 to 14.84

[3] EV: evacuated villages, NV: nonevacuated villages, NT: Narovlya town